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Low-Impact Infrastructure: Development and Design Potential for Surface Application Alternatives for Subsurface Infrastructure in Yellowstone National Park's Upper Geyser Basin

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LOW-IMPACT INFRASTRUCTURE: DEVELOPMENT AND DESIGN POTENTIAL FOR SURFACE APPLICATION ALTERNATIVES FOR SUBSURFACE INFRASTRUCTURE IN YELLOWSTONE NATIONAL PARK'S UPPER GEYSER BASIN

by

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ABSTRACT

Low-Impact Infrastructure: Development and Design Potential for Surface Application Alternatives for Subsurface Infrastructure in Yellowstone National Park's Upper Geyser Basin

by

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In sensitive and iconic landscapes, such as Yellowstone National Park's Upper Geyser Basin, construction and expansion of visitor services is hindered, and often blocked, by the potential for environmental damage that could occur during the installation of subsurface utilities. These utilities, crucial to the success of development, require an alternative method of installation when placed in locations requiring special consideration and protection.

Yellowstone, in particular, is faced with the responsibility of protecting limited hydrothermal resources while also providing access to the general public. Sub-surface utilities threaten this responsibility due to the unknown nature of much of the subsurface

geology in place. As such, development to accommodate increasing usage has been delayed, creating overcrowded conditions which do not enhance the visitor experience.

This thesis seeks to provide design solutions with the potential to alleviate many of the problems associated with development within the park. This task is complicated by the iconic stature of Yellowstone, as the visual appearance of the region could possibly be degraded by the inclusion of visible utility structures.

By utilizing a literature review exploring current engineering technologies found in utility corridor systems of northern climates and developing design alternatives exhibiting a more appropriate visual aesthetic, there is potential to preserve the delicate subsurface geology of Upper Geyser Basin while also allowing the necessary expansion of visitor services.

Surface application of utilities in Yellowstone is hampered by the need to protect these systems from severe seasonal climate extremes, as well as the potential damaging effects of corrosive hydrothermal gases, which can be either highly acidic or highly alkaline.

These utilidors, when implemented on a site specific basis, can solve the problem of utility connections to individual buildings by significantly reducing, or even eliminating, the trenching required for traditional systems. It is this excavation that poses a serious threat to the subsurface geology and hydrology of the geyser systems. However, the small scale solutions explored in this thesis would need further study to be implemented on larger scale projects.

This thesis deals primarily with the visual design of surface utilidors, with the physical feasibility of the design being considered at all times. This research divides the Old Faithful area of Upper Geyser Basin into several “zones,” and provides site specific design alternatives based on the visual resource requirements of those zones.

My research provides the National Park Service with alternatives to infrastructure design and implementation, even if these ideas and strategies at times conflict with previously established codes and best management practices (BMP’s). This is not intended to be an endpoint in the engineering and construction of surface utilidors, but instead the first step in designing flexible infrastructure alternatives that best fit the conditions at hand. The ideas put forth in this work are intended to be conceptual examples and ideas of a future direction to consider when considering development expansion in sensitive or iconic landscapes.

(143 pages)

PUBLIC ABSTRACT

Low-Impact Infrastructure: Development and Design Potential for Surface Application Alternatives for Subsurface Infrastructure in Yellowstone National Park's Upper Geyser Basin

Michael R. Pace

In sensitive and iconic landscapes, such as Yellowstone National Park's Upper Geyser Basin, construction and expansion of visitor services is hindered, and often blocked, by the potential environmental damage that could occur during the installation of subsurface utilities. These utilities, crucial to the success of development, require an alternative method of installation when placed in locations requiring special consideration and protection.

Yellowstone, in particular, is faced with the responsibility of protecting limited hydrothermal resources while also providing access to the general public. Sub-surface utilities threaten this responsibility due to the unknown nature of much of the hydrothermal system in place. As such, development to accommodate increasing usage has been delayed, creating overcrowded conditions which do not enhance the visitor experience.

Design of surface-level utility systems can help to alleviate many of the problems associated with siting and constructing new structures within the park. This task is complicated by the iconic stature of Yellowstone, as the visual appearance of the region could be degraded by the inclusion of visible utility structures.

By utilizing current engineering technologies found in the surface utility systems (utilidors) of northern climates and designing a more appropriate visual "packaging," there is potential to preserve the delicate subsurface geology of Upper Geyser Basin while also allowing the necessary expansion of visitor services. Surface application of utilities in Yellowstone is hampered by the need to protect these systems from severe cold in the winter, as well as the damaging effects of corrosive hydrothermal gases, which can be either highly acidic or highly alkaline.

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Michael R. Pace

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CHAPTER I

BACKGROUND

As the ideas of environmental protection and human understanding of the natural world continue to progress, more importance is being laid upon the ideas of system resilience. This concept of resilience, defined here by Walker and Salt (2006) as “the capacity of a system to absorb disturbance and still retain its basic function and structure,” has resulted in a way of thought scientists in resource protection have termed “resilience thinking.” This thesis directly relates to the general concept of “resilience thinking” in exploring and offering a different approach to infrastructure design, stressing an increased importance on preserving a system’s individual resilience while still providing the required level of services.

Since the establishment of the profession of landscape architecture, practitioners have dealt with the interface between utility and art. Frederick Law Olmsted, the founder of the profession, was noted for his skills at resolving difficult engineering issues while creating landscapes of beauty. “Service must precede art,” he declared, “since all turf, trees, flowers, fences, walks, water, paint, plaster, posts and pillars in or under which there is not a purpose of direct utility or service are inartistic if not barbarous. … So long as considerations of utility are neglected or overridden by considerations of ornament, there will be no true art” (Beveridge, n.d.).

In 1878, Olmsted’s ability to solve a complex problem related to drainage issues of Muddy River and Stony Brook into the tidal estuary of the Charles River in Boston, earned him the admiration of the city engineer and park commissioners, and ultimately the contract to design the noted “Emerald Necklace” park system that graces the city today. Whether it was his brilliant solution to handle traffic circulation conflicts in Central Park, or serious storm-water management issues at Riverside, Illinois, his designs were noted for their skillful resolution of engineering obstacles in an artful manner (National Park Service, n.d.).

The Issue

In September of 2012, a class visit to Yellowstone’s Upper Geyser Basin led to questions pertaining to environmentally friendly infrastructure development. Sensitivity to environmental conditions is an important planning consideration within the National Park Service, and the question originally posed by a park employee was “…but how do we develop services and run our infrastructure across delicate geology?” After pondering the question briefly and developing a rough solution/ area for research, a proposed thesis idea of surface infrastructure systems was discussed with landscape architects at the park. The idea was warmly received and it was agreed this was a needed area of research.

At question is how to develop aesthetic, safe and functional infrastructure systems in such a way as to not damage these hydrothermal systems. The situation is further compounded by the visual sensitivity of this iconic landscape, viewed by approximately 3 million visitors annually, as well as the wildlife habitat of the area (Meyer, 2008).

It is the viewpoint of this work that the development of alternative infrastructure installation techniques is crucial to the future improvement of resource protection and the ideas of resilience and sustainable development. Infrastructure is the foundation of development and Yellowstone National Park has an opportunity to lead in the promotion and development of ideas not typical of industry best practices. The lessons learned in generating alternative infrastructures systems can form the foundation of future advancements and improvements in societal capital developments (Walker & Salt, 2006).

It should be noted and highly emphasized that this work is intended to examine an alternative infrastructure concept the National Park Service may wish to consider. The conceptual utility diagrams that appear in this work are provided in support of the larger idea of surface utilities as a design option, and are not intended to represent fully engineered solutions. What is intended is to explore an alternative technique for replacement of aging infrastructure or the provision of new utilities to accommodate necessary expansion in a visually, historically, and environmentally sensitive manner.

Park History

The protection of Yellowstone National Park found its beginnings in 1872 with the passage of the Yellowstone Act. This legislation, which was "…dedicated and set apart as a public park or pleasuring-ground for the benefit and enjoyment of the people...", was intended to preserve scenic beauty, particularly the hydrothermal systems found in the region (Dilsaver, 1997; Sellars, 1997). This collection of geysers, hot springs, and boiling "mud pots" were found to be of utmost scenic value at a time of changing values of landscape use and protection (Wellman & Probst, 2004). While the public at large was beginning to accept and support the notion of resource protection, larger corporate and political interests, particularly the growing railroad industry, saw a golden business opportunity in the servicing of the public desire (Bartlett, 1974; Sellars, 1997).

Slow to achieve funded protection, the park suffered damage due to uncontrolled visitation and resource exploitation during its early years. Passage of the National Park Service (NPS) Organic Act in 1916 addressed this shortcoming, establishing the foundation for proper management and control of park resources (Wellman & Probst, 2004).

The period following World War II was a time of fairly drastic change for not only Yellowstone, but resource protection as a whole. Economic expansion with growth of personal wealth allowed for increased vacation and leisure time for the nation's citizens. Destination vacations began to increase and Yellowstone saw a burgeoning surge in tourism. As a response to this vastly increased visitation, and to celebrate the 50^{th} anniversary of the Organic Act, the National Park Service implemented Mission 66, expanding and modernizing service facilities in an attempt to meet the requirements of the park's enabling legislation (Secret Yellowstone, 2014). This developmental expansion occurred prior to the environmental revolution of the 1960's and much of the development to encourage and support increased visitation was not primarily focused on protecting the delicate ecosystem of the geyser basins.

With the growth of environmental awareness and understanding, the long-entrenched philosophy of utilitarianism began to weaken politically. The national parks began to shift roles from that of providing entertainment and leisure while protecting resources to that of protecting resources while also providing for leisure and relaxation (Wellman & Probst, 2004). The focus shifted, and knowledge has been gained that national parks must protect resources first if visitation and tourism is to exist in the same manner as has been historically known.

The environmental movement saw the advent of NEPA, the Clean Water Act, and the Clean Air Act; all of which have placed a responsibility on government agencies to ensure the adequate protection of natural resources. The National Park Service has assumed a leadership role as a facilitator and supporter of environmental research (Runte, 1997). This places the national parks in a unique position to facilitate the advent of new ideas and help guide the future direction of resource protection for the nation as a whole. No longer are the parks solely for recreation; they have become the proving grounds for future growth in knowledge, presumably free of bias and influence.

This emphasis has not gone unnoticed by the general public, or the scholarly community. As Ballantyne, Packer and Hughes (2009) discovered, park users realize the importance of environmental stewardship and are willing to sacrifice access for the greater environmental good. While restricted access may play a pivotal role in many protection plans, the more important message here is that the protection of ecosystem function is an important and expected function of park management by the general public.

The management of national parks involves a complicated and sensitive combination of agency mandates, policy directives, environmental protection and societal recreation expectations. On the surface, much of national park management seems focused solely on the management of ecosystems and the creation of accessible outdoor recreation opportunities; yet lurking just beneath the visible surface is a myriad of sensitive classified government regulations pertaining to the protection of federal installations and infrastructures.

Following, and partially due to, the First and Second World Wars, an increasing importance was placed on the protection of information deemed important to the security of national assets and systems. As time has advanced, the initial rationale for the classification of information relating to national security has progressed from the need to protect national resources from rogue/enemy nations to that of a more sinister threat; the surge of guerrilla tactics employed by terrorist individuals and organizations (Apostolakis & Lemon, 2005; Moteff, 2005; Moteff & Parfomak, 2004).

The potential of such threat has led to drastically heightened security concerns, particularly since the destruction of the World Trade Center in September of 2001 and has resulted in the passage of numerous laws and Presidential Executive Orders regarding the classification and dissemination of sensitive information. In recent years, entire departments such as the Department of Homeland Security have been created to oversee the security of this knowledge (Apostolakis & Lemon, 2005; Moteff, 2005; Moteff & Parfomak, 2004).

Public utility infrastructure is vulnerable to disruption by acts of terror and certain information must be classified to ensure its protection. Major trunk arterial infrastructure must remain concealed, protected or otherwise secured in order to satisfy the demands of not only internal departmental planners, but also the Department of Homeland Security and the National Security Administration.

Partially due to this history, NPS management and development is tightly controlled through policy and discovery and understanding of these numerous policies is crucial to the proper design of built landscape elements within Yellowstone.

Much of the infrastructure development in the park has occurred according to the existing knowledge of the times, and over the many years of growing and learning, development-supporting infrastructure was placed without a realization of the potential ground impacts or a good plan for future development expansion. This is not to say there was any form of neglect or malfeasance in the construction of the current infrastructure system, but simply to acknowledge that the complicated and permanent nature of buried utilities leads to a situation in which it is difficult to change direction once a system has been placed.

Also following the Second World War, Congress saw a need for passage of legislation intended to improve government clarity and transparency. This legislation, the Administrative Procedures Act, created a framework of policy outlining the processes government agencies must adhere to while creating planning documents. The Administrative Procedures Act is a minor yet important component of alternative infrastructure system design as many of the recommendations, suggestions and ideas may not necessarily follow long established best practices and protocols. This act, along with Section 106 of the National Historic Preservation Act, requires federal agencies to provide strong evidence to justify a departure from established practices in favor of new and possibly somewhat controversial solutions, while also considering the effects of their actions on historic structures, of which there are many in Yellowstone's Upper Geyser Basin.

Issues of Future Growth

Yellowstone's geyser basins are riddled with underground hydrothermal features, many of which are still unknown as to their exact location. There is speculation and some data to suggest that the water supply for these basins is recharged from the watersheds bordering the caldera environment (Marston & Anderson, 1991). Expansion and development to accommodate future growth of park visitation in Upper Geyser Basin, which includes the Old Faithful area, is possibly limited, and definitely concerning, due to the potential risk of damaging hydrothermal features during construction. If development in these areas is to occur in such a way as to promote the ideas of resilience and protect what is known to be the largest collection of active geyser systems in the world (Steingisser & Marcus, 2009), established rules of design and construction (best practices), typically derived in a fashion to promote safety and efficiency, should be instead focused on optimizing environmental health and sustainability (Walker & Salt, 2006). This is not to say safety and efficiency should be ignored, but rather resilience should be given the same level of planning importance.

As park visitation expands, so too must developed park resources. As stated previously, much of the developed surface of the park lies within sensitive hydrothermal basins. With knowledge lacking as to the exact extent of the deposits and the flow of groundwater, increased infrastructure development to support tourist activities has posed a damage risk to basin geysers. With the geysers being only one portion of a complex, intertwined system of hydrology, it is feared damage to even a small part of this hydrologic system could permanently damage geysers in the basin, such as Old Faithful (Steingisser & Marcus, 2009).

Development and expansion of park buildings is complicated not only by the sensitive nature of these basins, but also the nature of typical buried infrastructure (sewer, water, telecommunications, electricity, etc.) By placing these infrastructure systems above ground, in aesthetically well-designed “utilidors” (an above or below ground corridor used to transport multiple utility infrastructure systems) for example, damage to sensitive hydrothermal systems in the construction process can be avoided (Curiel-Esparza, Canto-Perello, & Calvo, 2004).

It will be necessary to develop systems capable of being replicated easily while also produced to meet the very specific needs of site specific installations. This may increase initial capital construction costs and, possibly, maintenance of systems which are more complicated than what current “best practices” provide. The trade-off, however, is improved protection of the geyser systems from increased tourist related development (Steingisser & Marcus, 2009) and an improved ability to manage the resources directly responsible for the creation of Yellowstone in the first place.

The exploration of alternatives for infrastructure placement and development, in an effort to improve park planning capabilities, is intended to provide options for infrastructure development within the boundaries of Yellowstone National Park which match the physical, historical and cultural standards of the park, while also helping to achieve the goals as set forth in the policy mandates of Yellowstone and the National

Park Service. By providing the Park Service with design options for surface utility infrastructure placement, one important step in this organizational and planning process can be accomplished.

Approach – Design Process

This thesis examines low impact infrastructure systems which will help further the National Park Service's ability to accommodate future growth, in an aesthetically acceptable manner, without damaging delicate environmental and geologic site features.

The process involved discovering precedence in cold region infrastructure design, researching the constructability of these "systems," understanding the current policy and regulatory framework of the National Park System (federal agencies in general), uncovering the historical and cultural design heritage (visual resource management) of Yellowstone National Park, while also accommodating the environmental and biological aspects of the region.

Imagery clearly depicting the known locations of hydrothermal resources and soil types played an important role in understanding existing site conditions. This information was used to determine suitability for constructed surface structures and allowed for a holistic approach to material and construction technique determination.

The primary focus of this work has been on developing these alternative systems within Upper Geyser Basin with the immediate area surrounding Old Faithful serving as the "project site." However, information regarding conditions not pertaining directly to Upper Geyser Basin has also been utilized as part of the research into determining which materials and building practices are best suited for the Old Faithful "scope of work."

This thesis begins with an extensive literature and practice review investigating current surface infrastructure transmission designs based on evidence and best practices. Existing strategies in cold and/or sensitive environments have been studied for precedence. In particular, Alaska was looked at closely for treatment of water and sewer infrastructure, as were northern communities in Canada, Scandinavia and Russia.

In order to gain an overall understanding of the Yellowstone environment, a further focused literature review informed the site analysis, based on actual current conditions and available National Park Service documentation. This literature review encompassed the weather and climate of Yellowstone National Park, the geothermal layout of Upper Geyser Basin, wildlife behavior which could affect construction design of landscape elements, historical overview of development in the basin, current utility infrastructure systems and technologies, and National Park Service design methodologies and requirements. Materials capable of withstanding the caldera environment were researched before finally developing transmission design strategies.

Potential impacts on visitor use, due to the creation of new surface infrastructure elements, were explored primarily through the gained knowledge of existing circulation patterns in Upper Geyser Basin. Placement of surface infrastructure has been proposed in such a manner as to help tourist navigation within the Upper Basin site, to the greatest extent possible, causing a positive benefit to recreational use of the area.

Several design studies, taking into account the geological, biological and political factors mentioned above are provided, including alternative routing corridors, built element cross sectional studies and visual resource studies. Visualizations of these proposals utilized graphic software such as Adobe Photoshop, Trimble SketchUp and AutoCAD. A brief report of findings, analysis and comparisons of the infrastructure system alternatives has been provided for future park planning and research.

To conclude, it must be noted projects concerning infrastructure are hampered by the classification of government infrastructure, installations and operations information following the attacks of September 11^{th}, 2001. While not ideal, this situation is unchangeable. For the purposes of this thesis, providing a product of information and conceptual ideas, the classified nature of existing infrastructure has had little bearing on the end results. Again, this thesis is not intended to be an engineering report on best practices. While all attempts have been made to be accurate with engineering requirements, it must be understood that the solutions derived herein are based in the realm of design and attempted to show feasibility. It cannot be stressed enough that accuracy of engineered elements within utilidors must be studied further in future works.

CHAPTER II

INVENTORY AND ANALYSIS

Geography, Geology and Hydrothermal Features

Yellowstone National Park lies within heart of the Rocky Mountains and includes the northwest corner of Wyoming, with lesser territory in eastern Idaho and southwestern Montana. Some of the planets oldest rocks are found in the northern-bordering Beartooth Mountains, which are not volcanic in nature. To the south of the Beartooths, the Absoroka Range, which is volcanic in origin, forms the eastern park boundary. The southern and western boundaries are made up of high, rolling plateaus and lesser ranges of mountains, including the northern portions of the Teton formations. The Gallatin Range, in the northwest corner of the park, completes the border of the Yellowstone region. This is a land of diversity in creation and form. From peaks reaching over 13,000 feet to high plateaus, rushing rivers, expansive viewscapes and a plethora of unique hydrothermal features, every area of the park is unique and interesting (Bartlett, 1989).

The vast majority of hydrothermal features within the park boundary, including Upper Geyser basin, are found within the Yellowstone Caldera, which is approximately 47 miles north to south and 28 miles east to west. These hydrothermal features are a geologic phenomenon 2.2 million years in the making and are a remnant of the last major episode of cataclysmic volcanic activity in the region which began approximately 600,000 years ago (Finn & Morgan, 2002; Fournier, 1989).

Geothermal locations are relatively rare on a global scale, and the systems within Yellowstone are among the most unique known to man. The complicated and delicate nature of hydrothermal systems is easily damaged by the effects of tourism, infrastructure development, geothermal energy development and changes to groundwater conditions (Fournier, 1989; Steingisser & Marcus, 2009).

New Zealand, at one point second in amounts of hydrothermal systems only to Yellowstone, has seen a 75% reduction in the amount of hydrothermal features, primarily due to the large amount of geothermal energy resource extraction which has taken place. Globally, geyser basins are being lost as geothermal energy prospecting increases to meet global energy demands (Steingisser & Marcus, 2009).

Yellowstone remains as the largest collection of geysers known and although there has been damage to the system due to tourism activities, little to no damage has yet been attributed to geothermal resource extraction. However, concern with this potential was great enough to warrant the passage of legislation regulating the further prospecting of geothermal resources in the Geothermal Resource Areas bordering the park on the west and north. Geothermal extraction development continues to be worrisome for issues pertaining to geyser protection (Steingisser & Marcus, 2009).

The nature of geothermal activity lends to extreme differences in pH and temperatures which can vary from basin to basin, depending on parent rock material and other geologic differences (Bargar, 1978). There are two primary forms, or types, of hydrothermal systems within the park.

The first of these two is termed a “hot-water system” in which the dominant feature is boiling water. These systems may be associated with geysers, which may involve pressure to create eruptions, or hot springs, which in general bubble and gurgle hot water out of the ground. These “hot-water systems” may deposit either an alkaline siliceous sinter, or a carbonate based travertine (Fournier, 1989; Kruse, 1997; Livo, Kruse, Clark, Kokaly, & Shanks, 2007).

The second form is a “vapor dominated system.” These vapor systems, commonly expressed as fumaroles, are created when the vent is not under pressure and is generally located in such a way the groundwater table is below the active vent zone. The hot boiling water creates steam that makes its way through the upper, dry rock and is expelled as a steam vent. These vents, due to the chemical interaction between the parent rock material and the hot steam, are generally characterized as an acid sulfate system and are commonly associated with kaolinite, alunite and other clay soils. (Fournier, 1989; Kruse, 1997; Livo et al., 2007). In a 1994 survey, the lowest pH found within the park was a pH of 2 at Monument Geyser Basin (Lewis, Palmer, & Kemp, 1994).

In general, the “hot-water” hydrothermal basin systems within the western half of Yellowstone (primarily within the caldera), including Upper Geyser Basin, contain a large water flow, high levels of silica and, chemically, are an alkali-chloride in composition (Channing & Butler, 2007). These waters are generally neutral to alkaline in chemistry and as the water cools, the silica precipitates out of solution creating the siliceous sinter deposits common with these non-acidic hydrothermal areas (Fournier, 1989; Hellman & Ramsey, 2004; Kokaly, Clark & Livo, 1998; Rodgers & Hampton, 2003).

These “hot-water” systems also create travertine deposits, referred to as “all nonmarine carbonate precipitates formed in or near terrestrial springs, rivers, lakes, and caves" (Sanders & Friedman, 1967 as cited by Fouke, et al., 2000) and are important geologic elements for historical records of climate and water chemistry, as well as water transport (Fouke et al., 2000). These deposits are created in areas high in a carbonate (such as limestone) parent rock material. The hot, carbon dioxide containing hydrothermal water carries creates a carbonated liquid that precipitates a calcium carbonate out of solution on the surface when the carbon dioxide is released into the atmosphere and pressure is reduced (Bartlett, 1989; Kruse, 1997).

Upper Geyser Basin itself (Figure 1), a part of the Firehole River Valley, is only approximately 1.8 square miles yet contains nearly 25% of the world's known geyser systems (Hellman & Ramsey, 2004). What is found in Upper Geyser Basin are alkaline basin bottoms, including the Old Faithful area, with more acidic "vapor-dominated" systems farther up the basin hillsides where there is reduced groundwater present. These vapor dominated systems are lower in silicas, higher in sulfates and may include steam vents, "mud pots" or "mud volcanoes" (Kokaly et al., 2007, Kruse, 1997). The distribution of soil types can be seen in Figure 2.

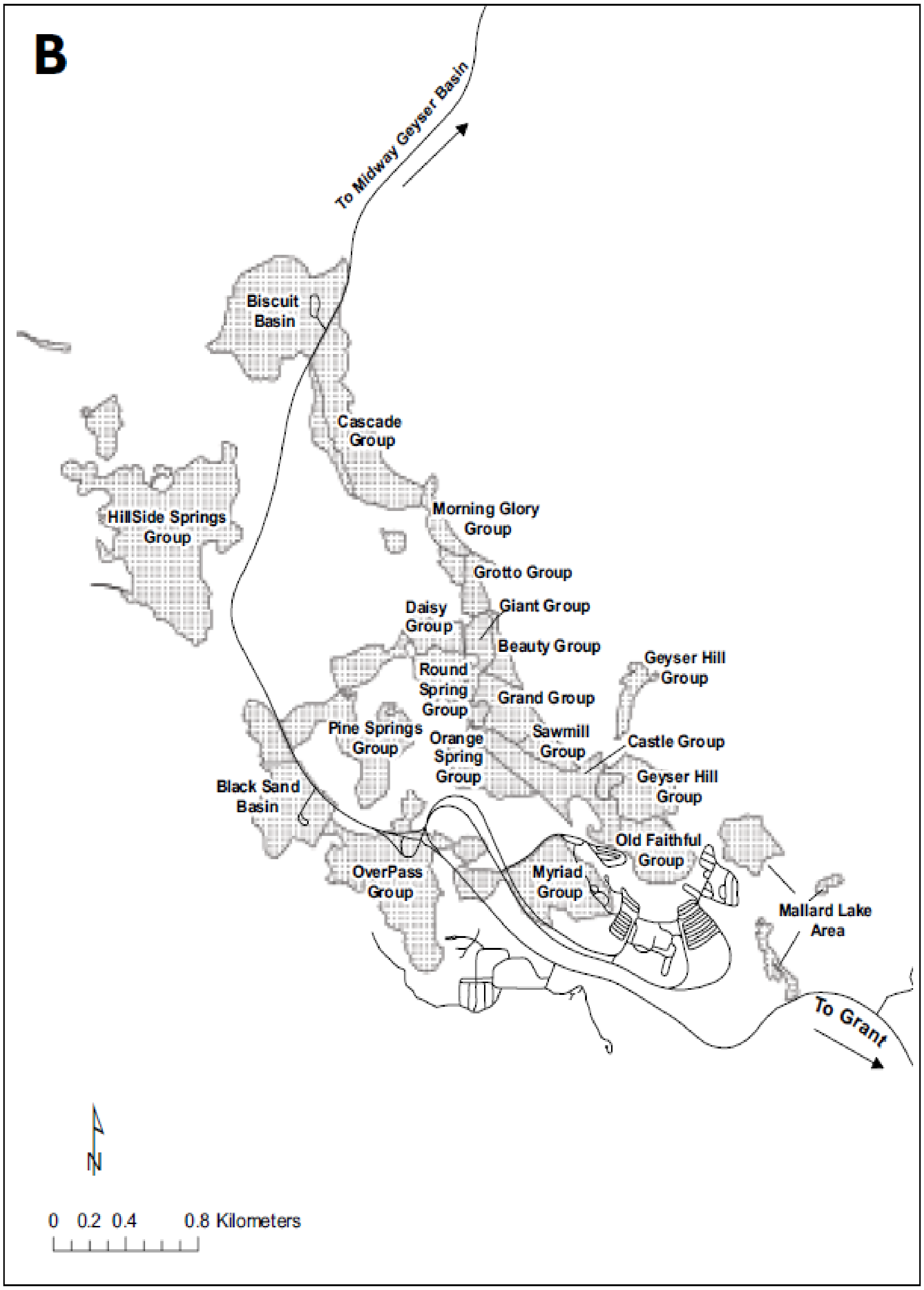


Figure 1. Upper Geyser Basin. 25% of the world's known geyser systems occur within this 1.8 square mile area (Hellman, M. J., & Ramsey, M. S. (2004). Analysis of hot springs and associated deposits in Yellowstone national park using ASTER and AVIRIS remote sensing. Journal of Volcanology and Geothermal Research, 135(1), 195-219.). Image credit: Jaworowski, C., Heasler, H., Neale, C. M., & Sivarajan, S. (2010). Using thermal infrared imagery and LiDar in yellowstone geyser basins. Yellowstone Science, 18, 8-19.

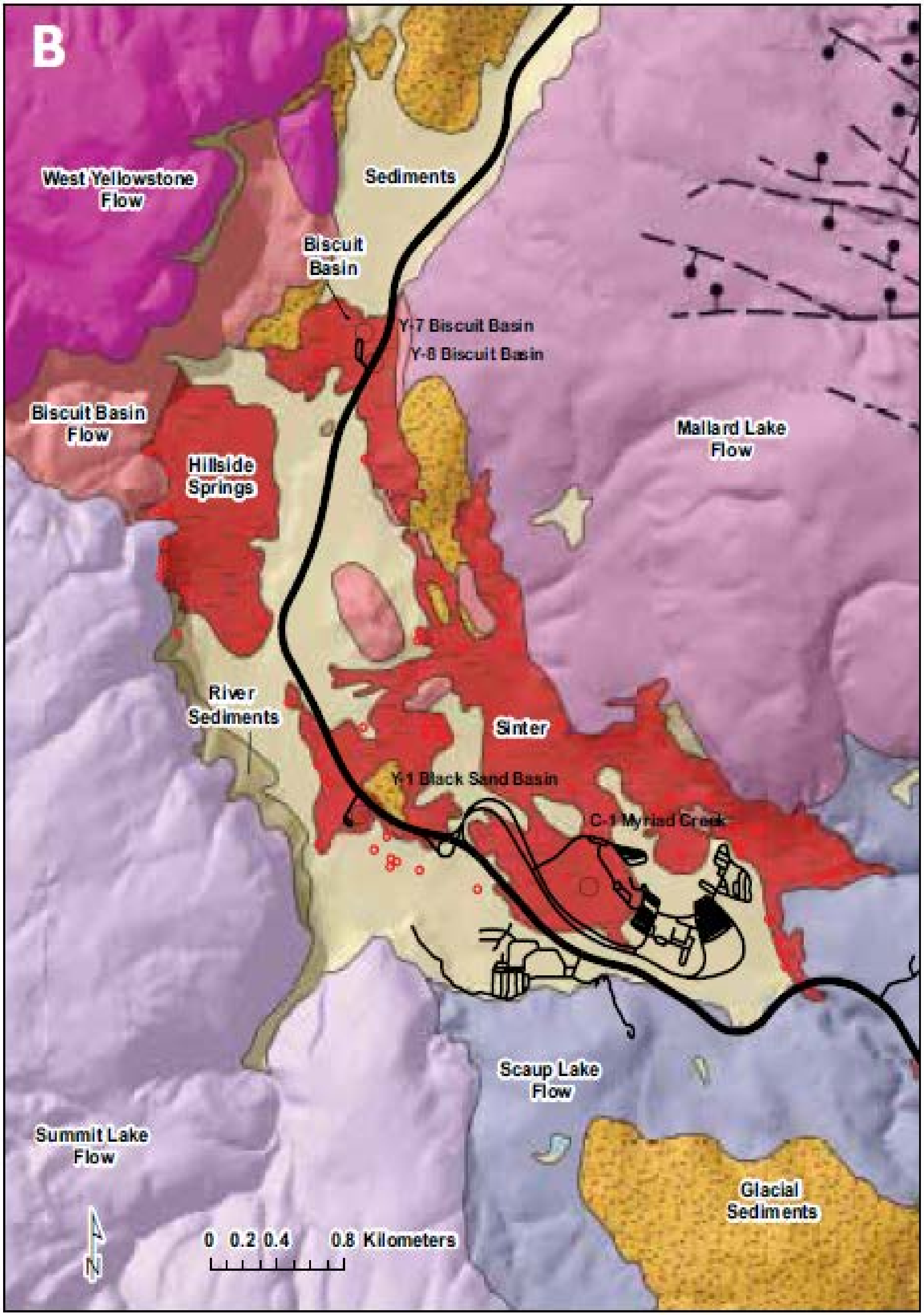


Figure 2. Upper Geyser Basin locational geologic soils and major types. As can be seen in this image, Upper Geyser Basin primarily consists of sinter and sediment derived soils, which tend to be alkaline in chemistry. Image credit: Jaworowski et al., 2010

Infrastructure impacts ground temperatures by directing heat and water along construction alignments, instead of allowing flow to be determined by natural processes and contours. LiDar imagery clearly depicts the effects of development on the dispersing of ground heat in Upper Geyser Basin. Figure 3 shows the effect of infrastructure on ground heat distribution in the developed areas surrounding Old Faithful. Figure 4 shows this effect on heat distribution at the location of the new Old Faithful Overpass construction site and in the basin as a whole. (Jaworowski, Heasler, Neale, & Sivarajan, 2010).

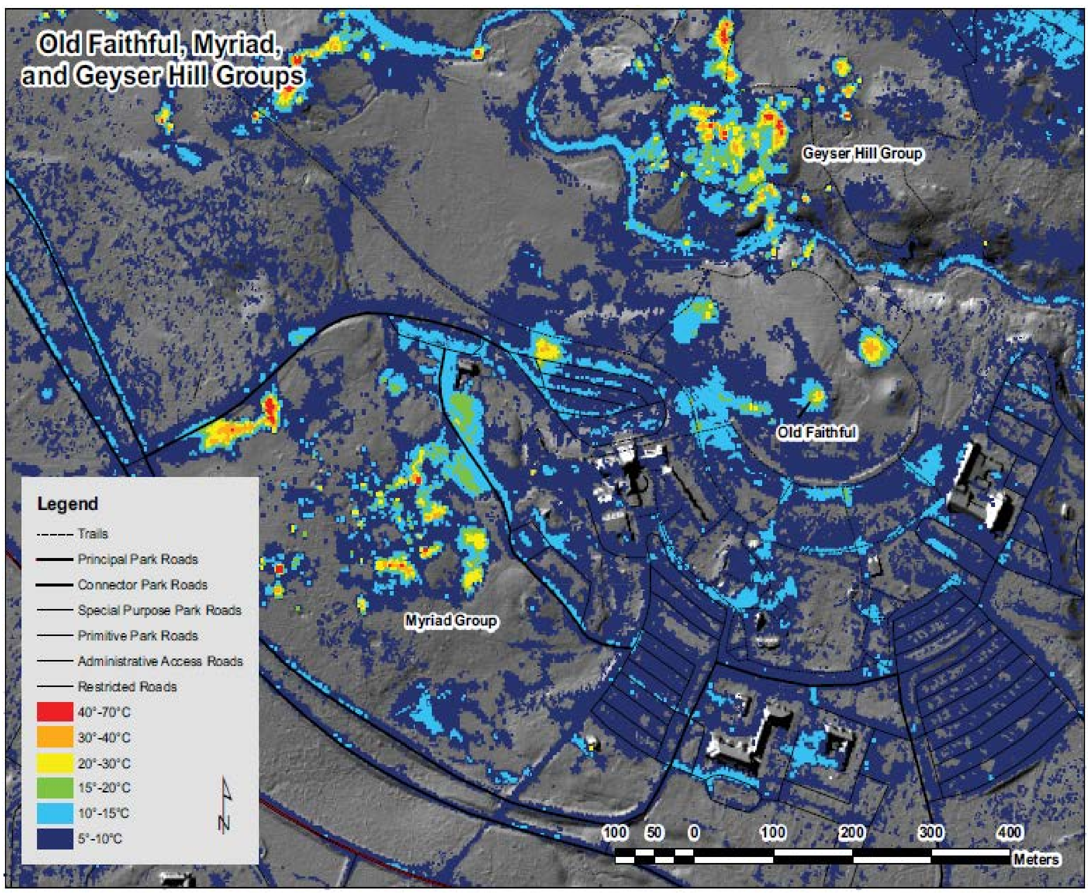


Figure 3. LiDar imaging depicting infrastructure effects on ground heat distribution surrounding Old Faithful development. Image credit: Jaworowski et al., 2010.

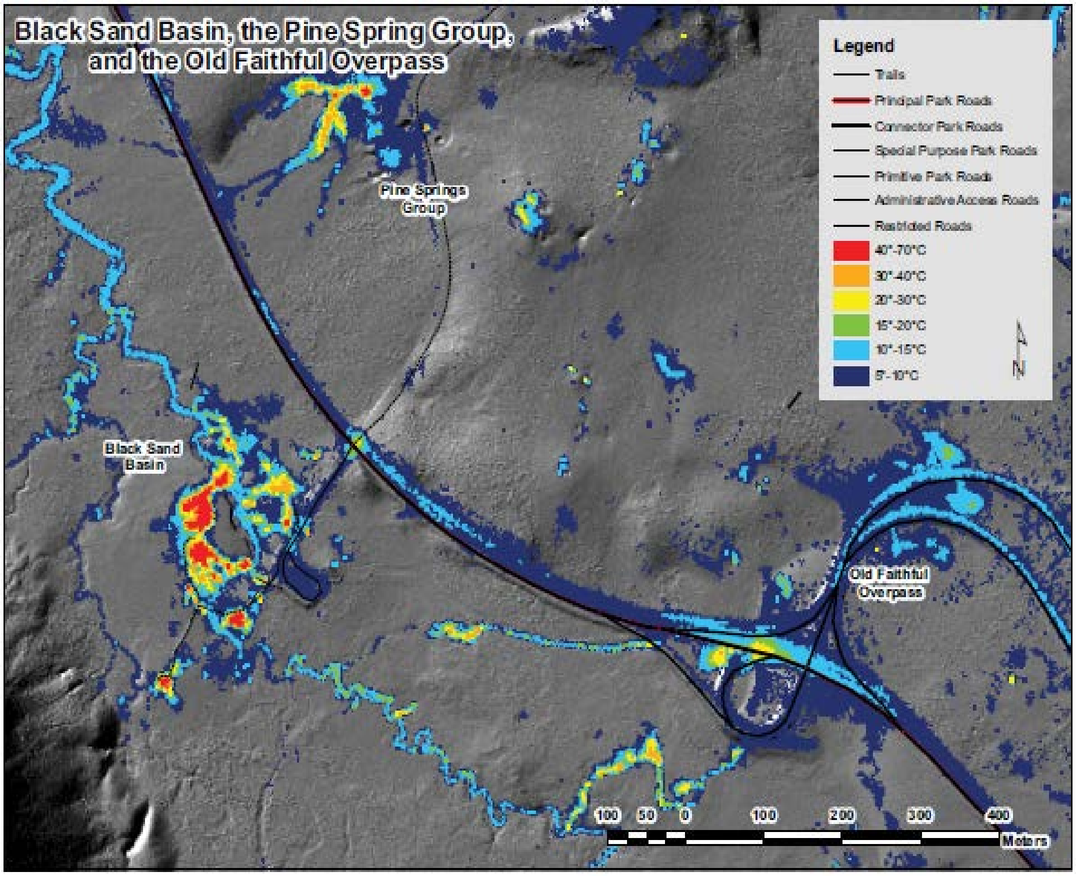


Figure 4. LiDar imaging depicting infrastructure effects on ground heat distribution in Upper Geyser Basin as a whole. Image credit: Jaworowski et al., 2010.

In order to adequately protect hydrothermal resources, hydrothermal basins must be viewed holistically as one working network of systems, and not individual "features" as they are commonly viewed (Jaworowski et al., 2010)

Wildlife

Yellowstone National Park is a significant and important ecosystem for numerous animal species, including several which are either threatened or endangered (NPS, 2000). A significant concern in the construction of utility corridors is the potential for impeding natural wildlife movement. As infrastructure, by its very nature, creates a linear corridor of unbroken material, special care should be taken to minimize the “trapping” of animals into corners, particularly where high numbers of tourists could make the animal feel threatened and incapable of escape. In some locations, utilidors could potentially be placed and designed in such a way as to guide migrating animals along a specific path towards historically defined gathering areas. In other instances, they could be constructed in such a way as to enable escape by easily leaping over the structure.

Natural lines of movement need to remain open, with pockets and recesses limited to the greatest extent possible. Long runs of unbroken surface infrastructure need to be limited in number in order to minimize the “alley” effect for both humans and wildlife and provide for egress of animals caught in the traffic routes normally associated with tourist visitation.

Another consideration relates to the potential impacts wildlife can incur on utility infrastructure. Bison horning and rubbing behavior is often times severe enough to dislodge telephone poles from the ground. With the height of this behavior occurring during the spring shed through the summer rut, surface landscape infrastructure elements do not have the protection deep winter snow depths provide (Bowyer, Bleich, Manteca, Whiting & Stewart, 2007; Coppedge & Shaw, 1997; McMillan, Cottam & Kaufman, 2000). This timing also coincides with the highest tourist visitation traffic (summer vacation season) and could possibly place tourists in the direct path of potentially aggressive, large animals drawn to the new landscape feature. With the mature weight of a bison male reaching as high as 2000 lbs., special attention to construction planning will be needed in this subject (Meagher, 1973).

Bison horning behavior, when considering man-made materials, has focused primarily on poles made of both wood and metal, although stone has also been used in these behaviors (Coppedge & Shaw, 1997). While Coppedge and Shaw (1997) discussed previous studies indicating aromatic wood species seem to be a preferred rubbing choice over non-aromatic species (Edwards, 1978; McHugh, 1958; Meagher, 1973), their studies instead indicated the preference of smooth barked Black Willow, Green Ash and Sycamore by bison when engaged in these behaviors.

The bear population in Yellowstone has increased in recent years to the point where there are approximately 150 Grizzly Bears (Ursus arctos horribilis) within the park boundaries and an unknown number of more common Black Bears (Ursus americanus) (Yost & Young, 2013). Although bears are a large, strong animal, their behavior and tendencies to avoid people and population centers would seem to dictate their presence around surface infrastructure would be cause for little concern, other than the occasional animal climbing or sitting atop a built landscape element.

The most common large mammal found within the park boundaries is the North American Elk (Cervus elaphus), with summertime numbers reaching upwards of 20,000 animals. As the summer season draws to a close, the elk’s antler cease to grow and the animals are driven to scrape off the fuzzy skin known as velvet. (Yost & Young, 2013). This scraping process, in preparation for the fall rut, may cause concerns for surface infrastructure design should the elk deem the structure suitable as an antler scratching post.

Yet another aspect of the wildlife/tourist/infrastructure interaction is that of visitor safety. While care needs to be taken to avoid the “trapping” of wildlife and providing for escape, surface utility corridors could also be constructed to enhance visitor safety. By potentially creating a fortified barrier incapable of being breached by, for example, bison, visitors could find safe refuge in the occurrence an overly aggressive animal decides to take issue with unsuspecting tourists.

Planners of utilidor systems must take into account the ability of these animals. Bison will generally not challenge barriers, but are strong enough to damage them if wanted, while elk, deer and moose easily clear barriers 5 feet in height (Gates, 2006). If surface infrastructure conduits/corridors are to act as a safety zone for tourists, these abilities need to be considered and planned into the conduit design. While it is unlikely a barrier could be designed large enough to prevent breach, or even to discourage the attempt, the simple ability of a tourist to escape the “line of sight” of an aggressive animal may be enough to prevent serious injury. Designing a conduit that meets these needs and fits within the aesthetic context of Upper Geyser Basin may be a difficult task to achieve at times, depending on the location and requirements of the infrastructure at hand.

While much attention and focus is paid to the large mammals of the Yellowstone region, smaller animals must also be thought of. Utilidor construction must discourage its use as a nest or den and prevent the use of materials, such as insulation, to be “mined” for uses outside of the element (e.g. nesting material), which could cause unending maintenance headaches for park managers and maintenance staff. This “small animal” element is important considering Yellowstone is noted for having the largest diversity of mammals in the contiguous United States, including mice, chipmunks, wood rats, coyotes, foxes, lynx, rabbits, beavers, porcupines, amphibians, and countless birds and insects (Bartlett, 1989; NPS, 2005; Yost & Young, 2013).

Climate

In Yellowstone, the average high January temperature is almost 29 degrees Fahrenheit, in contrast to the summer high average temperature of almost 80 degrees Fahrenheit, found in the month of July. The record low temperature for Yellowstone National Park is -65 degrees Fahrenheit. The average annual precipitation is 15 inches of water per year, with an average snowfall of 72 inches, but this is variable depending on geographical location and elevation within the park (NPS, 2013).

Climate change will play a role in future park development, as Yellowstone heats beyond historical norms. Overall warmer average winter temperatures and lower snowpack totals and changing climatic regimes are placing established natural systems at risk due to variable and extreme conditions (Saunders, Findlay, Easley, & Christensen, 2011). This same unpredictability could be extrapolated to include the vulnerability of built elements containing cold-sensitive infrastructure to severe weather and sudden prolonged cold snaps.

It is theorized and predicted the historical snowfall pattern in northern high-latitudes will be altered as climate change continues to advance. The prediction is that high latitude forest will experience a shortening of the snow season, leaving the ground snow-free for a longer period of time and possibly a reduced snow depth (Lawrence & Slater, 2009; Mellander, Lofvenius, & Laudon, 2007).

This reduction in snow season and depth has the potential to increase soil frost depth penetration during extended periods of severe cold (Edwards, Scalenghe, & Freppaz, 2007; Hardy et al., 2001). Depending on the severity of frost penetration, existing subsurface utility systems may be risking damage due to unplanned climatic changes. While Lawrence and Slater (2008) concur with this ground temperature assessment, they also bring forth the point that a shortened snow season could also possibly increase soil temperatures due to the increase in solar heating on exposed ground surfaces.

Yellowstone climate predictions include drier summers with warmer, milder winters (Bartlein, Whitlock, & Shafer, 1997). Winter precipitation is generally projected to increase, yet Romme and Turner (1991) claim winter precipitation is difficult to predict and claim the Yellowstone region will see a net decrease in the amount of moisture during the winter months.

Greater soil cold penetration following late rains has the potential to lead to a condition known as “concrete frost” which in turn would result in a reduced ability of the soil to absorb winter precipitation. Concrete frost creates an impenetrable barrier for precipitation and results in decreased groundwater recharge and increased runoff (Edwards et al., 2007; Hardy et al., 2001).

The opposite of concrete frost is a condition known as “granular frost.” This type of frost forms under freezing conditions when the soil has not been moisture saturated.

As a result, air space remains between the ice crystals and melt-water is allowed to percolate between the open spaces (Edwards et al., 2007; Hardy et al., 2001).

This alteration of the “normal” hydrologic cycle may result in a changed groundwater regime and flow, increasing the fragility of hydrothermal features and stressing even greater the need for their protection.

Ultimately, climate change may be wildly variable and planners need, more now than ever, to consider the “worst-case scenario” when designing infrastructure systems, both surface and subsurface. Deep snowpacks can no longer be counted on to provide adequate thermal insulation to surface structures or soil profiles. Late and/or shallow snowpacks may increase frost depth penetration, while early snowmelt may result in increased initial runoff followed by an early warming of the soil profile. Increasing overall winter temperatures cannot be counted on to protect against unpredictable cold snaps (Edwards et al., 2007; Hardy et al., 2001; Lawrence & Slater, 2008).

By acknowledging the possibilities of climate change and planning for future conditions, Yellowstone managers can help lessen the damage caused by drastic environmental shifts by increasing ecosystem resilience and allowing the evolution of an ecosystem to play out on a more holistic and natural course, instead of rushing into a hard-to-repair alternative stable state (Melnick, 2012; Scheffer et al., 2001).

Visual and Social

The visual and social inventories of the Old Faithful area can best be described as unique. Although located in what would be considered a forested settings, barren expanses of sinter, punctuated with the rising steam of hot springs and geysers, intertwines and wraps around every facet of the visitor experience.

Architectural structures are a heavy, not-quite overly dominant aspect of the experience, transporting the visitor back in time to the Golden Age of National Park exploration, development and acceptance. Stone construction and aggressive timbers are softened by the deep green of the surrounding hillsides and in other places extended by the expanses of young forest still recovering from the massive fires of the late 1980's.

The Old Faithful area is a busy place during the summer months, with large amounts of not only personal vehicle traffic, but tour busses and camp trailers as well. At times chaotic in appearance, the overarching natural themes of wildness and North American exploration continues to elevate above the negating effects of modernity.

The National Parks, with Yellowstone in particular, are a true American creation. At the time of their formation, the United States was but an adolescent on the stages of world power. The progression of wildland preservation, the advancement of ecological protection, and the development of a system provided to secure the mental well-being of the nation's citizens were a shining beacon of a cultural coming of age (Wellman & Propst, 2004).

The social ramifications of Yellowstone's original intent and creation continue to be enhanced by the park's emphasis on scientific knowledge and public education. As can be seen in the names of buildings such as the Old Faithful Visitor *Education* Center, the societal realization that progress is a never ending vision is preserved with future generations being the recipients of thoughtful planning and foresight.

CHAPTER III

PROGRAM ANALYSIS – UTILITY SYSTEMS

Current Utility Systems - Trenches

The current state of infrastructure transmission technology has remained relatively unchanged for the last 60 years. Under normal (temperate climates, etc.) conditions, the quickest, cheapest and safest implementation strategy for most applications is to trench and bury water and sewer infrastructure. Wired electrical and communication lines are also often buried for increased protection and visual integration, but this results in a higher installation cost versus traditional overhead routing.

Best management practices suggest wet utility lines must be located in separate trenches, or at the least, vertically separated within the same trench. This requirement varies depending on the jurisdictional codification of utility infrastructure, but is intended to prevent cross-contamination between potable water supply lines and sewage disposal lines. There is precedence of practice, however, which allows for minimization of this barrier to design. In northern Canadian communities it is acceptable, at times, to “bundle” water and sewer lines not only in the same trench, but also within the same protective insulating jacket (Smith, 1986). Buried as needed to get below the active permafrost or seasonal frost line, trenched installation of utility systems can be neither cheap to install nor easy to repair, if needed (Smith, 1986). Trenching of infrastructure is currently employed within Yellowstone and will not be discussed further as a solution, as the purpose of this work is to avoid disturbance of the subsurface soil profile.

Current Systems - Surface Routing

At times, wet utility surface piping systems are employed in arctic conditions. These systems consist of a single, insulated pipe. Sometimes supported above the ground surface, generally through the use of pilings, these surface systems can also be laid directly on the ground surface, depending on the infrastructure and other site location requirements (Grainge, 1969; Smith, 1986). It is this idea of a singular insulated pipe system, free from bury or encapsulation (other than insulation) which allows for the transmission of piped fluid systems to be employed in varying conditions, such as conveying water or sewer lines under the superstructure of a bridge.

Current Systems - Utilidors

Northern, frozen regions, in an attempt to avoid deep trenching, often rely on the construction of utilidor systems, both above and below ground, where finances allow for the increased initial capital cost of construction. After initially gaining favor in the mid-twentieth century (Grainge, 1959), there has been little advancement in the visual integration of utilidor systems, particularly in an aesthetically appealing design fashion.

In Alaska and Northern Canada, the use of utilidors is common. As can be seen in Figure 5, these types of systems do not take into account the visual aesthetic of the system. While apparently acceptable for their locations, their design aesthetic is wholly inappropriate for visually sensitive locales such as a national park.

Figure 5. Utilidor system in Inuvik, Northwest Territories, Canada. Image credit: http://us.fotolog.com/geogblog/37155873

Russia also has used surface utilidors for Siberian and other northern applications of infrastructure transmission corridors. Often times constructed of wood, concrete, and metal, these transmission corridors share the same visual qualities as those in northern North America. Purely functional by design, they lack any sense of aesthetic concern for the surrounding environment (Figure 6). Again, while they may be acceptable for Siberia, Yellowstone is not the place to encourage this style of visually obtrusive development.

Figure 6. Utilidor in Arkhangelsk, Russia. Image credit: GoogleEarth

Northern Scandinavian infrastructure corridor routing includes utilidor construction as well. Again, these systems are visually obtrusive and often times present a physical barrier to efficient and safe pedestrian movements. As can be seen in Figure 7, Norwegian utilidors offer a high tech, modern day solution to utilidor construction. The construction materials appear to be state of the art, yet they continue to lack any sense of refinement or design aesthetic. They appear to be afterthoughts, placed only because the severe climate justifies their existence.

Figure 7. Utilidor in Longyearbyen, Svalbard, Norway. The insulated line directly on the ground surface is “kinked” to account for thermal expansion and contraction (McFadden & Bennett, 1991). Photo credit: Michael Timmons.

Much of this lack of design consideration can be blamed on construction requirements when dealing with situations of permafrost. Pilings often must be placed in such a way to support the utilidor and prevent movement due to permafrost melting or winter heaving. These pilings represent a huge obstacle to aesthetic design. Fortunately, permafrost is not a factor in Upper Geyser Basin, even though consideration does need to be given to more seasonal frost heave.

Most cold climate utilidors, whether surface or subsurface, are heated to prevent cold damage to the utilities within (Muller, 2008). As cold winter temperatures are a concern in the Yellowstone region, insulation and heating systems are in important design component.

Current Systems - Design Parameters and Limitations

Enclosing utilities in a small scale utilidor raises many concerns for the protection of utilities in addition to insulation from the cold. The use of utilidors, whether of the large-scale tunnel or small-scale surface variety, can result in placing numerous types of utility systems within close proximity. The placement of sewer and water lines needs careful consideration as cross contamination and water/electrical conflict risks are greater within an enclosed structure. While large-scale utilidors afford more protection in the area of this conflict risk abatement, small-scale systems need to either utilize separate systems for differing utility types, or create sealed chambers which can act as a physical barrier between the components.

Physical damage due to maintenance activities, natural phenomena or accidental vehicular conflicts is a much less easy factor to consider due to the random and unplanned nature of the events. Careful consideration should be taken to ensure the proper infrastructure solution is placed in the proper contextual setting. A more delicate approach to infrastructure transmission may be acceptable in a pedestrian-only setting, yet may be completely inappropriate anywhere near locations involving vehicular traffic.

Long-term forms of damage due to corrosion stemming from electrolysis and condensation are also not to be overlooked, and should be determined by a civil engineer, who would best understand material specifications based on individual design solutions and geologic locations.

Utilities - Water

Pressurized potable water systems will not need any further modification to their installation design, other than choosing appropriate construction materials for their specific location and ensuring against winter freeze conditions.

Pipe sizing, friction loss, and flow velocities are fairly generic, utilizing standardized computations which are shown in Table 1. Be aware these numbers can and will vary depending on individual piping systems and associated pressures. More important for the design of small scale utilidors is the planning and implementation of providing for continuous circulation within lateral lines, avoiding “dead-ends” where possible. This circulation, according to Molly Nelson of Yellowstone National Park, is already a design factor in the park water systems and helps to prevent stagnation and freezing pipes (M. Nelson, personal correspondence, February 11, 2014). Due to space requirements, this may necessitate the use of multiple utilidors feeding the same singular structure.

Table 1
Water Pipe Size, Flow and Friction Losses

Pipe Size =	2 Inches	3 Inches	4 Inches	5 Inches	6 Inches	8 Inches
Volume Flow	50	100	175	300	400	1000
(gal/min)						
Volume Flow	3000	6000	10500	18000	24000	60000
(gal/hr)						
Velocity	4.9	4.4	4.5	4.9	4.5	4.9
(ft/sec)						
Friction Head	4.2	2.2	1.6	1.5	1	0.9
(ft/100ft)						
Friction Loss	1.8	0.9	0.7	0.6	0.4	0.4
(psi/100ft)						

Information in this table is using Schedule 40 PVC pipe. Velocity and flows must remain below 5 ft/second. If needed, calculate Pressure loss using Equivalent Pipe Length Method. (http://www.engineeringtoolbox. com/pvc-pipes-friction-loss-d_802.html)

Water systems will also need careful attention paid to points of connection, backflow prevention, stop waste and shutoff valves. These important components of a pressurized system will need to be planned so as to provide proper function and access when maintenance or repair is needed.

Utilities - Gravity Sanitary Sewer

No less crucial to the design of surface utilidors is the understanding and study of “wet” drainage lines such as sanitary sewers. Due to the need to always keep costs reasonable, gravity sanitary sewer lines are usually the first choice in choosing waste disposal technologies. As the name suggests, gravity sewer lines are controlled by the downward pull of gravitational forces. In its most basic implementation, wastewater flows from high to low and must carefully follow landforms and contours. This system also results, oftentimes, in deep trenching; a requirement of maintaining elevations below grade yet still arriving at an ultimate low point.

As can be seen in Figure 8, gravity sewer systems are constructed to maintain minimum slopes, reflecting variable input design factors. As a general rule, the smaller the diameter of sewer pipe, the greater the slope requirements to avoid the deposition of suspended solids in the waste stream which could potentially develop pipe-clogging sludge. This sludge deposition will ultimately cause sewer flow problems, increased maintenance and premature failure due to increased production of caustic hydrogen sulfide gases (USEPA, 2002)

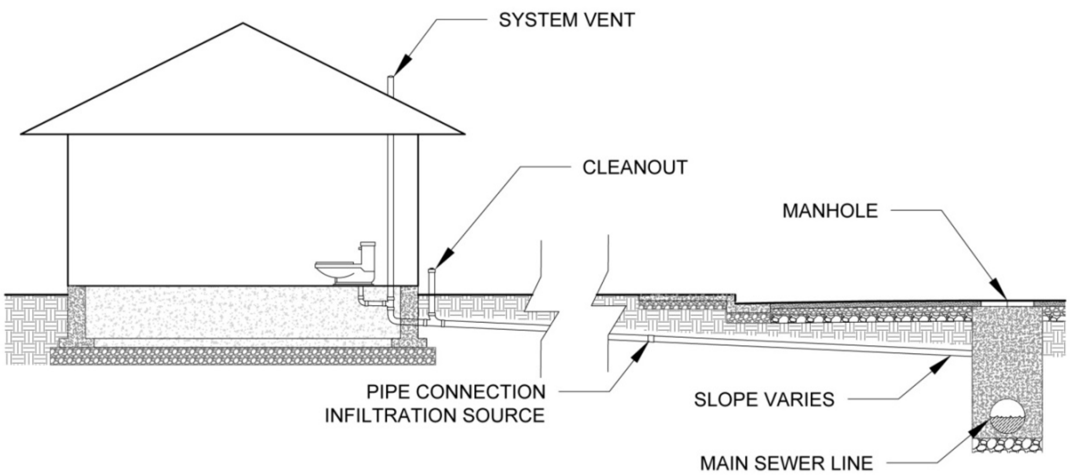


Figure 8. Typical gravity sanitary sewer installation.

Normally, typical buried gravity sanitary sewer lines must be sized to not only carry away source point water input (toilets, sinks, etc.), but also to include potential groundwater infiltration and stormwater surge as well. As sewer pipes often consist of interlocked lengths of concrete or plastic piping, there are often gaps in connectivity that allow groundwater to infiltrate the piping system. Stormwater often times enters the system through manholes or storm drains during periods of heavy rainfall or snowmelt. This additional “wet period” influx of water is a crucial component to sewer system design, yet is also extremely difficult to accurately predict due to its variable nature (USEPA, 2008).

Fortunately, for this work, this additional flow influx will not be an issue for short run surface utilidor connection runs as sub-surface groundwater infiltration is not applicable to a surface piping system and Yellowstone utilizes surface sheet flow and infiltration stormwater management. Instead, surface sewer lines could be seen as a “flow-saving” measure for end-point sewage treatment.

Table 2 provides the flow rates of various sizes of sewer pipe and the associated slope percentages of the pipes. As it is not always possible to place surface utility systems in such a way as to utilize surface landform contours, this information will be helpful when determining non-traditional sewer applications, such as force mains, and the requisite sizing differences when considering utilidor space allocations.

Table 2
Gravity Sewer Pipe Capacities at Assumed Half-Volume Flows

Carrying Capacity of Sewer Pipe (gallons per minute)								
Size of Pipe	Decline per 100 ft of Pipe (ft)							
(inches)	1	2	3	6	9	12	24	36
3	13	19	23	32	40	46	64	79
4	27	38	47	66	81	93	131	163
6	75	105	129	183	224	258	364	450
8	153	211	265	375	460	527	750	923
9	205	290	355	503	617	712	1006	1240
10	267	378	463	655	803	926	1310	1613
12	422	596	730	1033	1273	1468	2076	2554
15	740	1021	1282	1818	2224	2464	3617	4467
18	1168	1651	2022	2860	3508	4045	5704	7047
24	2396	3387	4155	5874	7202	8303	11744	14466
27	4407	6211	7674	10883	13257	15344	21770	26622
30	5906	8352	10223	14298	17717	20204	28129	35513
36	9700	13769	16816	23760	29284	33722	47523	58403

http://www.engineeringtoolbox.com/sewer-pipes-capacity-d_478.html

The actual process of designing sanitary sewer pipe sizes for this work is not necessary as the information needed (pipe sizes) has been provided by the Park Service. Normally, sizing processes would be based on standardized flow volumes for given sewer-feeding a structures, such as toilets, sinks and other such modern amenities.

Utilities - Pressurized Sanitary Sewer (Force Main)

As there is currently a pressurized force main system in place within Upper Geyser Basin, this would be the most feasible solution for this project as the maintenance staff is already familiar with its operational needs.

A forced main sewage system works on the principle of liquid material being forcefully “pushed” through a smaller diameter sewage pipe. Detailed in Figure 9, a force main system requires the use of a collecting tank and pumps to move liquids through the system.

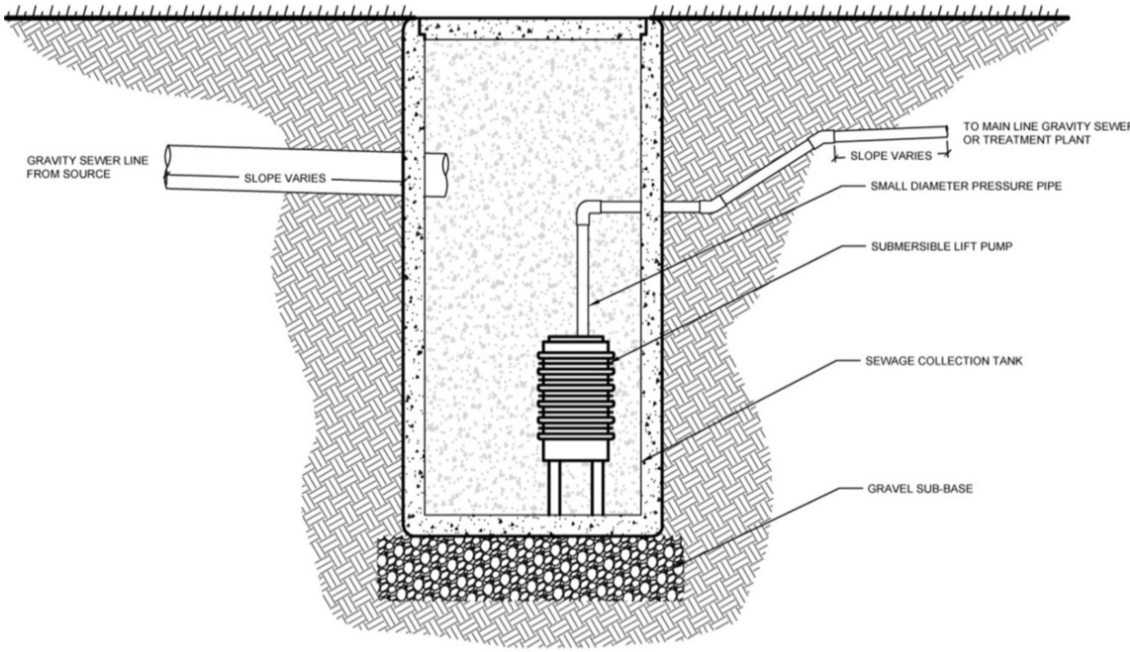


Figure 9. Typical force main cross section. Gravity sewer lines feed a collection tank which pumps effluent uphill to either a gravity main line or sewage treatment plant.

There are two primary types of force main sanitary sewer systems. The first is known as a STEP system, in which septic tank effluent is partially treated before being pumped into the pressurized system. The second type is known as a grinder pump system, in which effluent is gathered in a storage tank and pumped into the system with little-to-no pre-treatment. The “grinder” in the name of this system denotes the capacity in which this is accomplished, as the pump itself performs the pre-treatment by grinding solids into transmissible slurry. As is seen in Figures 10 and 11, the grinder pump system allows for a smaller scale of installation, as a large septic tanks are not required, instead being replaced with smaller pump-containing storage units grinder pump systems also allow for smaller diameter discharge pipes as effluent solids have been broken down through the grinding process (National Small Flows Clearinghouse, 1996).

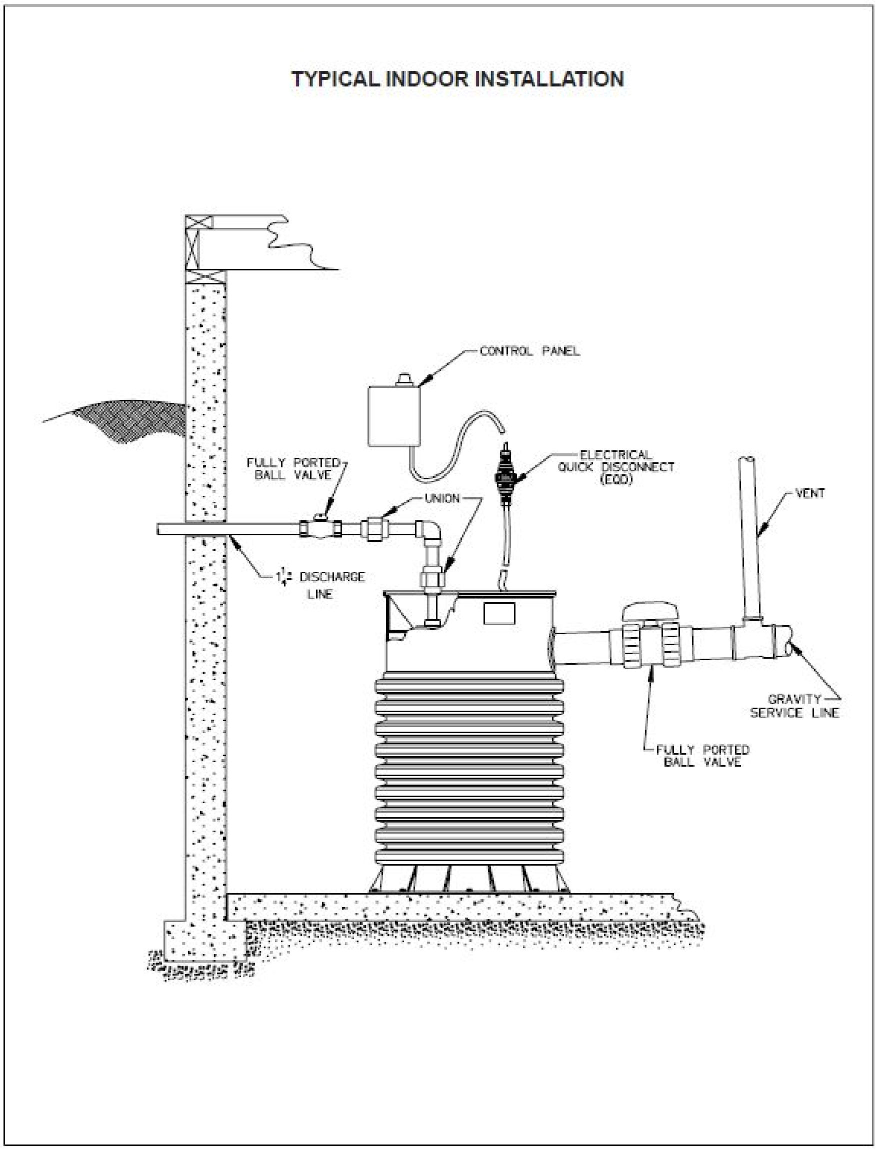


Figure 10. Typical indoor installation of force main grinder pump and storage tank (Environment One Corporation, n.d.)

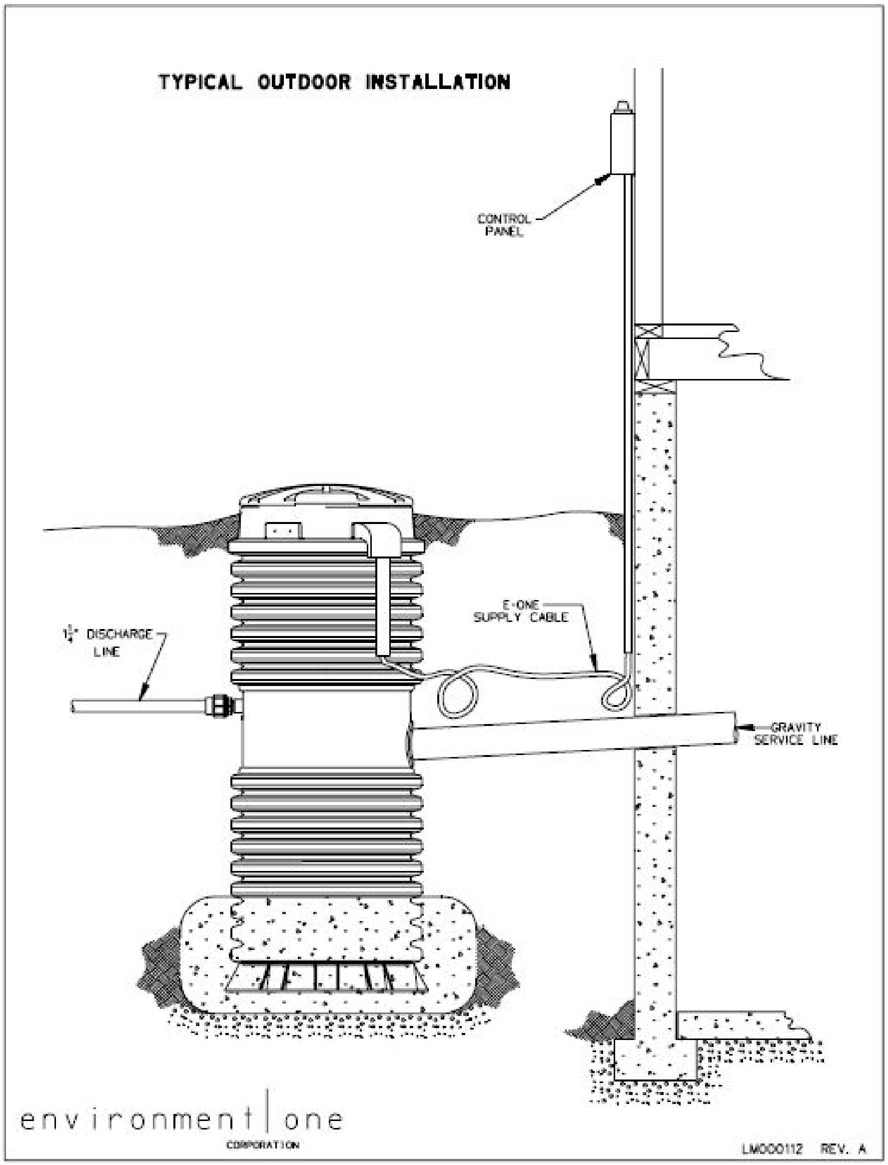


Figure 11. Typical outdoor installation of force main grinder pump and storage tank (Environment One Corporation, n.d.)

There are numerous components of force main design which need to be considered. In order to avoid pump and pipe system damage from water hammer, it is important to avoid pumping fluid downhill. Empty air space between the pump and the point of discharge creates pump and pipe vibrations (cavitation) which can cause component damage and possible failure. The system should be designed in a fashion maintaining upward slope, so that between pump cycles remaining effluent will continue to fill the piping system without draining away. As well, the system needs to be design to minimized “swales” in the line and the creation of trapped air. This entails locating the appropriate valves and vents in suitable areas based on final site location and line design.

Pump life must be considered and the tank needs to be an appropriate size to limit the number of on/off cycles. If the tank is too small, the pump will cycle too often, thereby reducing its expected service life and resulting in increased maintenance and repair costs.

There is a minimum velocity of flow which needs to be considered. If flows fall below approximately 2 ft/sec, suspended solids will settle out of solution and create blockages due to sludge deposition. Alternatively, pipe systems and joints can be damaged if velocities are too fast. As with other piped fluid systems, velocities must remain below 5 ft/sec to avoid component damage and failure. As a design consideration in systems containing pressurized liquids, thrust blocking needs to be designed in areas where the momentum of the moving internal fluid could potentially damage piping joints and connections.

Even under ideal operating conditions, sewer pipe maintenance is inevitable. As such, the cleaning of pipes should be planned for. The use of “pigs” (a cylindrical cleaning tool, forced through a piping system to remove accumulated debris from piping walls) is a common maintenance tool, and the sanitary sewer system should include both an entry and exit cleanout point for such.

Utilities - Vacuum Sanitary Sewer

Vacuum systems work on the principle of “pulling” a plug of liquid material through the sewage system. Detailed in Figure 12, this system, much like a force main system, requires the use of a centralized station, only this centralized station is farther from the point source sewage input. In order to move these “plugs” of sewage, vacuum systems rely on air pressure differences created at a more centralized vacuum station similar to centralized vacuum cleaners found in homes. With one vacuum controlling multiple sewage collection points, the complexities of designing this type of system are vast. Multiple release valves located in valve pits must be created, pipes must be constructed in such a way as to create “reformer pockets” (see Figure 13) and the vacuum station itself is generally sited in a downhill, or lower, elevation location to avoid having to overcome large head pressure differences (Averill & Heinke, 1974, PDHengineer, n.d.).

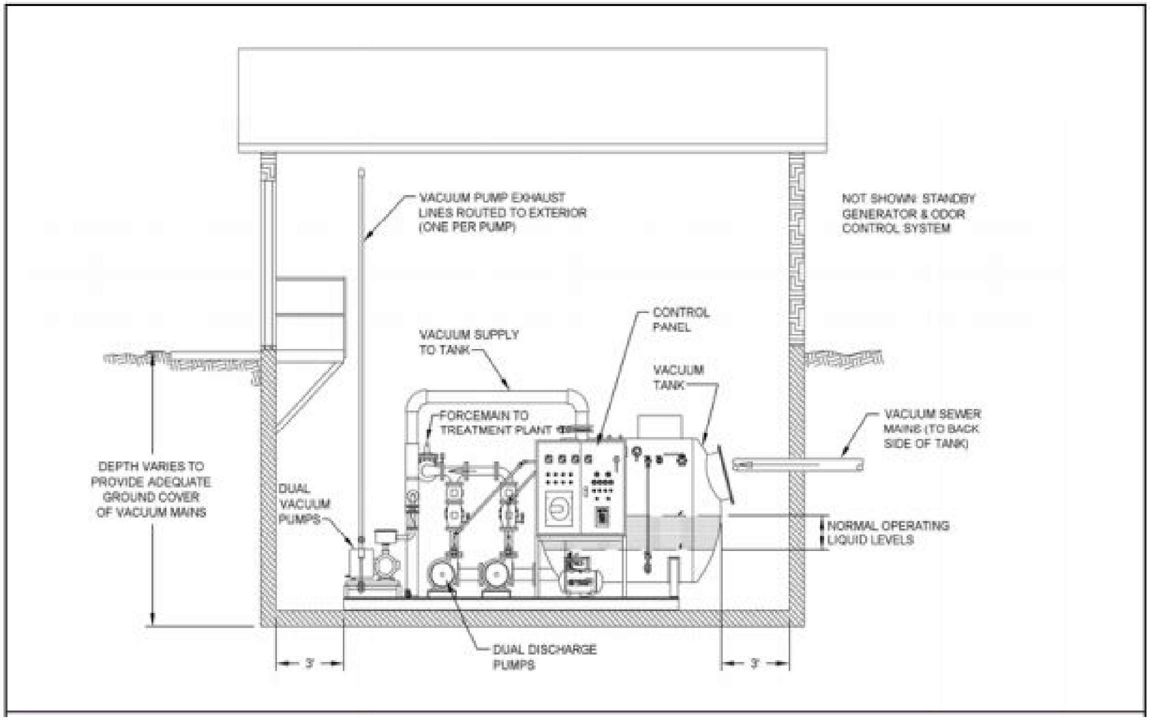


Figure 12. Typical vacuum sewage pump details (PDHengineer, n.d.).

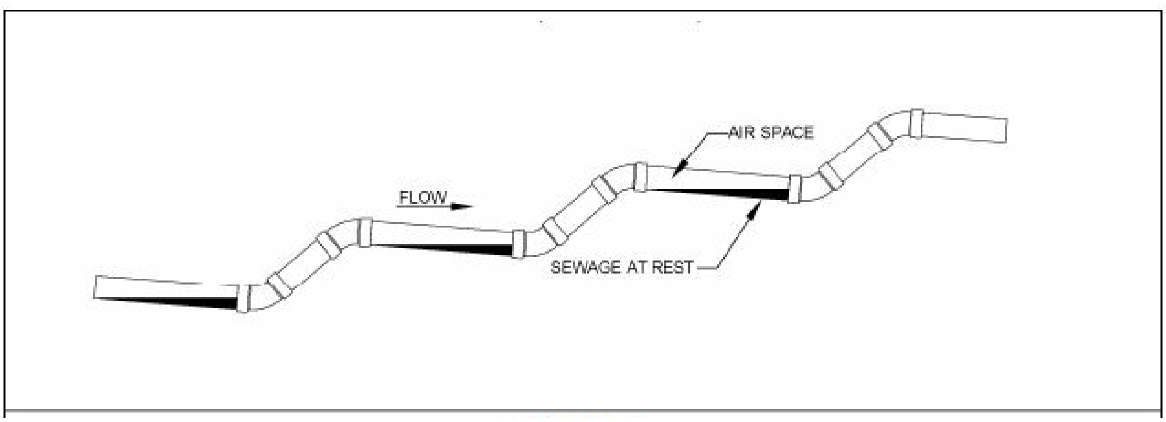


Figure 13. Typical Vacuum Sewage System Reformer Pocket Design (PDHengineer, n.d.)

The complexities of a vacuum system will generally preclude their use on a small site scale, such as short run utilidors connecting singular buildings to mainline sewage systems. Even when sited in appropriate locations, oftentimes vacuum systems will still need to be used in conjunction with another system, either force main or gravity, to deliver sewage effluent to a treatment center (National Small Flows Clearinghouse, 1996; PDHengineer, n.d.). Vacuum systems are limited in placement as their effective operating lift is limited to approximately 20 feet in elevation difference and valve and valve pit components have a high failure rate, requiring increased maintenance and repair (Averill & Heinke, 1974; National Small Flows Clearinghouse, 1996).

Utilities - Electrical and Wired Communications

Calculations for exposed wire transmission primarily include the amount of expansion and contraction experienced based on expected weather conditions. This calculation will also apply to wired systems found within a small scale utilidor if internal temperatures are not kept at a constant. The freezing of condensation within utilidor pathways is a potential threat to the longevity of wire sheathing and needs to be considered in utilidor design. The generation of heat through electrical line loading may possibly allow for installation of line conduits free of extraneous heating sources (Gill, 1974).

Expansion loops to account for expansion and contraction due to seasonal changes in utilidor temperature are an important component of wire transmission planning and will ideally be placed at the beginning and end of the utilidor runs. Due to the short run lengths of the utilidors in this work, this should be an acceptable placement location for this crucial element of line placement.

Placement of wired lines within the confines of a utilidor will protect these systems from the damaging effects of snow, ice, falling trees and other natural hazards.

While this could also be achieved by direct burying of these lines, again, the purpose of this work is to eliminate or significantly reduce the need for infrastructure trenching.

Utilities – Propane and Natural Gas

Natural gas or propane lines are perhaps a bit more controversial due to the potentially dangerous nature of the system. Any surface application of gas lines will need to be carefully considered as to the appropriateness of its location, routing and overall exposure. Routing a gas line above ground where conflicts between automobiles, snowplows, etc. are possible, is highly discouraged unless other protective measures are first employed. The visible gas systems currently in place in the Old Faithful area are generally relatively close to their endpoint destinations and conflicts should be able to be kept to a minimum.

Freezing is not such a consideration with gas lines as gasses have extremely low freezing points, however, as anyone who has used a small propane cylinder has discovered, condensation on the surface of the gas line may create issues with water vapor inside the utilidor structure. Increased venting in structures containing gas needs to be a design consideration. Engineering considerations must also adequately deal with potential damage due to seismic activity. While a utilidor structure may provide for additional flexibility when compared to a direct bury line, easily accessible shut-off valves and ability to vent gas from within the structure quickly and safely needs to be designed into the system in the event of a ruptured line.

It would be beyond the scope of this thesis to even attempt to suggest safe engineering solutions to surface placement of gas lines, but it would be reasonable to assume from the standpoint of design, that these systems could be engineered safely to utilize the space provided by such a system. Ideas put forth herein will need careful exploration by qualified industry representatives prior to final design.

Materials - Concrete

Concrete is one of the most common and available building materials for the construction of utilidor infrastructure systems. However, due to the volatile and inconsistent nature of geyser basins, application of concrete needs to be carefully researched and applied to avoid premature aging, breakdown and replacement.

Perhaps two of the largest issues pertaining to concrete use in Upper Geyser Basin relate to the corrosion of reinforcement (rebar) found within the structure and the deterioration of the concrete itself due to acid attack.

Corrosion of interior structural reinforcement is normally due to the introduction, through capillary action, of chloride ions through the use of de-icing or other naturally occurring salts (CCAA, 2009). This introduction of chloride ions can also occur through the reaction of the concrete with carbon dioxide (Obla, Lobo, & Lemay, 2005). Described as a carbonated front, chloride ion advancement reduces and eventually eliminates the protective barrier (passivation) concrete provides reinforcing bar. In order to provide this protection, concrete pH must remain above 9.4. Carbonated fronts acidify concrete, lowering the pH below the levels required for passive protection (CCA, 2009; Dolton & Hannah, 2006).

The porosity of the concrete structure can greatly affect the speed at which carbonated fronts move through the outer layer, eliminate the passivity concrete provides, and begin to attack the surface of steel reinforcement (CCAA, 2009; Mehta, 1999; Obla et al., 2005). This porosity can be significantly reduced through the careful mixing of concrete and forming of structures, eliminating airspace within the slurry and providing sufficient material coverage of rebar so as to slow the advance of carbonated fronts. By incorporating concrete sealers to the finished structure, a barrier can be formed, further preventing the ability of chloride ions from creating a front in which deterioration can begin (CCAA, 2009; Mehta, 1999; Obla, et al., 2005; Montes & Allouche, 2009).

Corrosion protection of structure reinforcement can also be attempted through the use of special coatings and treatments of the bar itself. Epoxy coated bars are intended to provide barrier protection from carbonated fronts (Mehta, 1999), although there is question as to their effectiveness (CCAA, 2009). Galvanized coatings on rebar also appear to help reduce corrosion, although the protection afforded appears variable depending on the alkalinity of the concrete. Chromate-reduced concrete mixtures appear to increase the protective defenses afforded by galvanization, and is a common requirement in the Northern European Nordic countries (Fratesi, 2002).

Concrete by its nature is highly alkaline. If improperly placed in contact with highly acidic soils or liquids, particularly sulfates, the ensuing geochemical reactions will quickly deteriorate the visual and protective features of the concrete, exposing the delicate infrastructure to unwanted physical and environmental hazards (Attiogbe & Rizkalla, 1988; Roziere, Loukili, Hachem, & Grondin, 2009).

Options are available for the treatment of concrete to be placed in environments containing high acid levels (below a pH of 6.5). There are numerous materials capable of allowing concrete to achieve an acid resistant characteristic. By altering the content ratio of Portland Cement in the concrete mixture to include low-calcium containing geopolymer materials containing class-F fly ash, for example, acid resistant concrete can be achieved (Bakharev, 2004; Bakharev, Sanjayan, & Cheng, 2003; Montes & Allouche, 2009).

Weather plays an important role in the strength and durability of concrete. Successive and numerous cycles of freezing and thawing results in a weakening of the compressive strength and increase in the amount cracking and spalling, which would lead to an increase in the speed at which carbonated fronts can reduce the passivation of the internal steel reinforcing bar. (Lee, Shih, & Chang, 1988; Mehta, 1997). While this damage may not necessarily result in structural failure, it can result in increased maintenance and premature replacement rates.

If properly applied, concrete is an ideal material to house utilidor infrastructure services in a safe, environmentally friendly fashion. The need for careful design consideration cannot be overstated, as the materials required for construction of concrete structures may not necessarily be the most ideal from an environmental perspective. Table 3, compiled by P. Kumar Mehta (1999), organizes concrete technologies into five categories relevant to concrete usage and planning.

Table 3

Suggested Ratings for Recent Advancements in Concrete Technology (Mehta, 1999)

Identification of the technology	Complexity of the technology	Initial cost of materials and construction	Life-cycle cost	Environmental friendliness of the product	Future impact on the concrete industry
Macro-defect-free cement pastes and mortars	High	High	High	Poor	Negligible
Chemically-bonded ceramics	High	High	Unknown	Poor	Negligible
Reactive powder mortars	High	High	Unknown	Poor	Negligible
Superplasticized, concrete with or without silica fume	Moderate	Moderate	Low	Moderate	Moderate
Self-compacting concrete	Moderate	Moderate	Unknown	Moderate	Moderate
Superplasticized, high-volume fly ash concrete	Low	Low	Low	Excellent	High
Superplasticized, high-volume slag concrete	Low	Low	Low	Excellent	High
Corrosion-inhibitors	Moderate	High	Unknown	Poor	Unknown
Epoxy-coated reinforcement	High	High	High	Poor	Unknown
Surface coatings for concrete	High	High	High	Poor	Unknown
Cathodic protection of the structure*	High	High	High	Poor	Unknown

Materials - Piping

Piping is an important component of surface utilidor systems. Many products are available, including concrete, iron, and plastic. The following chart outlines the major pipe materials and their associated characteristics. While concrete and metals have historically been popular choices for piping systems, the materials listed below are limited to the various families of “plastics.” While specific situations may warrant the use of metal pipes, it is the opinion of this author that more split-resistant (freezing) plastics are preferable. Ideally, piping capable of being extruded in long lengths will be used, minimizing the number of joints which must be properly solvent welded, sealed and insulated. Listed below (Table 4) is a relatively comprehensive, though not all-inclusive, listing of the available materials and their associated properties and characteristics.

Table 4
Common Pipe Materials and Characteristics (Corr-Tech, 2002)

POLYVINYLS

PVC (Polyvinyl Chloride): The most common and cheapest of the plastics. Chemically inert, corrosion and weather resistant, high strength to weight ratio. 40 years of successful use in temperatures up to 140°F. Joining methods include solvent welding, threading (schedule 80 only) or flanging.

CPVC (Chlorinated Polyvinyl Chloride): Used for corrosive fluids at temperatures up to 210°F. Chemical resistance is comparable to PVC, non-combustible, one-sixth the weight of copper, low thermal conductivity. Joining methods include solvent welding, threading and flanging.

POLYOLEFINS

Polypropylene (Homopolymer): The lightest thermoplastic piping, high strength, high chemical resistance, withstands temperatures to 180°F. Resistant to acids and bases, particularly know for resistance to sulfur compounds. Joined by coil welding and socket heat welding.

Copolymer Polypropylene: Excellent dielectric and insulating properties, high chemical resistance and strength, temperatures up to 200°F, high abrasion resistance and high elasticity. Joined by butt and socket fusion.

LDPE (Low Density Polyethylene): Lower strength, temperatures to 140°F, generally used for food handling equipment, tanks and dispensing equipment. Joined by hot gas welding.

HDPE (High Density Polyethylene): More rigid and less permeable than Low Density Polyethylene (LDPE). Temperatures up to 160°F, good resistance to abrasion and caustic materials. Joining methods include hot gas welding.

XLPE (Cross-Linked High Density Polyethylene): Also known as PEX Pipe. Superior stress-crack resistance, extremely high impact resistance, temperatures up to 160° F, most common use is for outdoor service large tanks. Cannot be hot gas welded. Avoid oxidizers, but overall good chemical resistance.

FLUOROPLASTICS

PVDF (Polyvinylidene Fluoride): High strength, abrasion and distortion resistance. Temperatures to 280°F, Resists acids, bases and organic solvents. Not recommended for strong caustics. Joined by thermal butt, socket or electrofusion.

Halar® (ECTFE) Ethylene Chlorotrifluoro Ethylene: Excellent resistance to acids, chlorine, solvents and aqueous caustics. Wide temperature range up to 340°F. Radiation resistant. Joined by thermal butt fusion.

FEP (Fluorinated Ethylene Propylene): Commercially available since the 1960's, high dielectric and chemical resistance properties, operating temperatures of -65°F to +300°F. Melt-extrusion manufacturing allows for high project flexibility.

PFA (Perfluoroalkoxy): Similar to characteristics of FEP, but offers higher working temperatures to 500°F and improved stress and crack resistance and increased tubing flex-life.

Materials - Insulation

The proper choice of insulating materials is a crucial consideration of successful utilidor design. Two key insulations commonly used in the construction trades are spun fiberglass and polyurethane foams. Condensation can be a problem within enclosed utility piping systems (Choudhary, Karki, & Patankar, 2004) and varying insulating materials respond differently under those conditions.

Spun fiberglass is considered to be a porous insulation and is normally installed with a vapor retarding jacket which is intended to prevent water and moisture from working its way *into* the insulation material. However, this barrier jacket does little to prevent moisture originating from *within* the insulation, such as what would be sourced from pipe condensate. There are products, however, that have been design to transport, or “wick,” this moisture from the pipe surface to the exterior of the insulation (Choudhar et al., 2004).

The significantly diminished (if not completely negated) insulating values of waterlogged spun fiberglass expose its weakness when placed in a condition of low airflow and condensation. Fiberglass insulation is also a space consuming and bulky insulation that may be difficult work with in a surface utilidor system.

The second popular insulating material, polyurethane foam, is much more resistant to the effects of water intrusion and associated insulation-damaging effects. As a non-porous insulation, the thermal conductivity of rigid polyurethane foams is minimally affected by immersion in water (FERPFA, 2006).

Polyurethane foams are also excellent insulators which consume significantly less space than that of fiberglass. With insulating abilities to -196 degrees Celsius, polyurethane foams are currently employed in the insulation and protection of pipelines, as their characteristics lend to a neat and efficient insulating system (Figure 14) (Demharter, 1998).

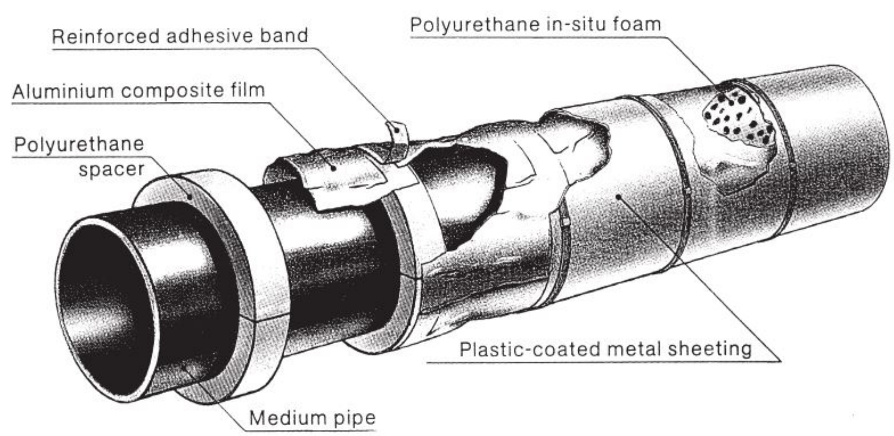


Figure 14. Typical pipe insulation system utilizing polyurethane foam (Demharter, 1998).

There are several companies utilizing this insulating material in their "engineered-to-meet-the-job" insulated piping product lines. These products, such as those provided by Perma-Pipe (Figure 15) and Rovanco (Figure 16) can be designed and manufactured to meet the exacting and rigorous requirements of the Old Faithful area (Rovanco, Inc., 2014; Perma-Pipe, Inc., 2014).

Polytherm® Specifications
High Strength Fiberglass Jacket
Spray Applied Polyurethane Foam Insulation
Above or Below Ground Applications
Engineered to Job Specs? : YES

Temp. Range: -320̊ F to 250̊ F
Max Pressure: Carrier Pipe Dependent
Pipe Sizes: ½" – 36"; 20'- 40' Lengths
Heat Trace Available? : YES

Figure 15. Perma Pipe, Inc. product specification.

Insul-8® Specifications

Multiple Options for Outer Jacket
Spray Applied Polyurethane Foam Insulation
Resistant to: Chemicals, Salt, Vermin, Moisture

Temp Range: -350̊ F to 250̊ F
Pipe Sizes: ¼" – 36"
Arrives at Job 95% Complete
Heat Trace Available?: YES

Figure 16. Rovanco, Inc. product specification.

Heat trace wiring is an important component of the insulating system of surface utilidors. This heat trace wire is necessary to provide the needed boost to pipe temperatures in the event severe cold conditions create a below-freezing thermal equilibrium. Heat trace is a common addition to pre-engineered piping systems and can easily be incorporated into a utilidor system.

Materials - Wood

Wood can be an important design material if one is attempting to maintain a rustic style or keep within the historical and cultural style of a place, such as Yellowstone. In use for centuries, wood is an affordable and attractive building material. However, for the purpose of modern utilidor structures, wood may need to be left to the realm of accenting, versus structural support.

Wood is affected by both the weathering process (discussed briefly below) and the decay process. Weathering is a natural process, initially begun (in wood) with the introduction of UV rays to the material surface. While weathering will eventually break down wood, it is a slow process that can take decades and only works on the surface layers of the material. Decay is a more destructive process which affects the entire thickness of the wood structure. Decay is caused by fungi that release enzymes into the cellular structure of the wood, metabolizing the broken down components for food. This process, under the right conditions, could destroy a wood structure or component in as little as a few years (Williams, 2005).

Table 5
Decay Resistance of Wood Product Species (USFS, 1967)

Very Resistant	Moderately Resistant	Nonresistant
Baldcypress (Old Growth)	Baldcypress (Young Growth)	Alder
Catalpa	Douglas Fir	Ashes
Cedars	Honeylocust	Aspens
Black Cherry	Western Larch	Basswood
Chestnut	Swamp Chestnut Oak	Birches
Arizona Cypress	Eastern White Pine	Buckeye
Junipers	Longleaf Pine	Butternut
Black Locust	Slash Pine	Cottonwood
Red Mulberry	Tamarack	Elms
Bur Oak		Hackberry
Chestnut Oak		Hemlocks
Gambel Oak		Hickories
Oregon White Oak		Magnolia
Post Oak		Maples
White Oak		Red/Black Oaks
Osage-Orange		Pines
Redwood		Poplar
Sassafras		Spruces
Black Walnut		Sweetgum
Pacific Yew		Sycamore
		Willows
		Yellow Poplar

When designing and building with wood, it is necessary to take into consideration the cost of the product, the maintenance required for longevity and the natural decay resistance varying species naturally exhibit. Table 5, above, lists this decay resistance of common forest wood products.

Pressure treated lumber, while a common material in construction is not recommended here solely due its propensity to leach chemicals, such as copper chromate, into the surrounding profile. While not necessarily a major concern, the sensitive nature of the Old Faithful area would tend to preclude, if at all possible, the use of materials which may harm delicate ecosystems.

Weathering

The effects of weathering play a major role in the design of surface utility systems. As the nature of utilities can place a person in harm's way, the durability of a utility transmission system is crucial. All materials must be able to withstand rigorous environmental conditions and must be equally durable in severe conditions. Potentially overall higher temperatures, due to climate change, may result in a more seemingly favorable environment for built landscape elements containing cold-sensitive infrastructure, but as Hall et al. (2002) point out, it is not necessarily cold which causes damage, but instead the cyclical change in temperature, between warm and cold, which create weathering problems. Heat drives the weathering process, mobilizing water and the general weathering process, while the quick change to cold temperatures then freezes the water and creates weathering damage.

Thermal stress is considered to be the cumulative and aggregate result of numerous "freeze-thaw" cycles, each of which is too small to cause much damage. Frost action is a common example of a freeze-thaw cycle which causes this stress (Hall, 1999). If climate change creates a volatile and unpredictable climate pattern, it is reasonable to suspect weathering damage could *increase* in a "warmer" environment.

Although thermal stress can affect nearly every aspect of constructed development, it is especially hard on concretes and stones. Weathering processes involving cyclical freeze-thaw patterns is increasingly damaging the more reduced the capillary pore structure of the material. Concretes and stones with coarse, large capillary pores withstand freezing better due to the ability of the water to escape the pore, rather than becoming trapped and exerting pressure against the capillary walls (Winkler, 1968).

CHAPTER IV

FINDINGS AND DESIGN PROPOSALS

Design Standards and Guidelines

The design standards adhered to by the National Park Service are an important component of this work. Much of the design aesthetic could arguably be attributed to beginning with Olmstead's firm belief that the National Parks visual beauty should be protected from the damaging effects of multiple use management. Not necessarily arguing for environmental protection, his aim was to preserve scenic beauty. Architecture, from this standpoint, needed to blend in with the surrounding landscape (Sellars, 1997). This was eventually supported in the language of the Lane Letter and eventually the Organic Act's statement of purpose (Sellars, 1997; Wellman & Propst, 2004).

With the establishment of the National Park Service in 1916 under Stephen Mather, the need for the professional services of architects and landscape architects was acknowledged by the organization. Their task was to ensure that new construction within the park system fit in a "harmonious manner" (Sellars, 1997). The Organic Act of 1916 mandated the protection and preservation of scenic and natural resources, and this priority guided the design decisions of new development. During the New Deal Era, funding increases and the leadership of landscape architects Thomas Vint and Conrad Wirth led landscape architecture to become a powerful driving force in the development of the National Park System (Sellars, 1997).

The “rustic” architectural style developed during this early era involved the use of “stone and rough-hewn wood,” assembled with a craftsmanship which can only be achieved through large amounts of inexpensive labor (USDA, 2001). In the Old Faithful area, this rustic style was developed in the pre-automobile era and was heavily influenced by the Adirondack Style of architecture. This design style was based in the remote settings of eastern United States forested regions and the architectural popularity of the Swiss style chalets and hostelries. (USDA, 2001; McClelland, 1998).

What the Park Service developed through its early years of development was an idea that the park system should represent, to the greatest extent possible, the values of the country as a whole. As a source of national pride, the national parks movement developed a concept unique to the world, and provided the United States with a legacy to protect the natural and cultural heritage of a nation. In order to preserve this heritage, visual scenery, both constructed and natural, became the driving force behind enhancing the visitor experience. As a result, the National Park Service has developed, through the years, an expansive set of visual design standards to perpetuate the vision of the early park system (Crystal, Dorrance, Hall, Propst, Schmid, & Sell, 1993; Wellman & Propst, 2004). These design standards are intended to provide development which “complements the natural or historic setting” of the park in which the development is occurring (NPS, 1990).

Design materials are crucial to proper planning and development. Barriers, walls and fences, though not necessarily desirable in a natural setting, are required in certain situations (NPS, 1990). When built, it is paramount that they consist of materials native to the area in which they are being designed. In order to maintain the historic rustic design aesthetic established in the early park years, this will normally include primarily stone and wood elements. Stone offers a sense of permanence over that of wood and should be used in areas of increased development. Long stretches and runs of fencing or barriers of any kind should be kept to a minimum to avoid a distracting lineal visual element in the landscape. When adjoined or in close proximity to an existing structure, the design elements of that structure should be extended to the associated wall or barrier (Good, 2003).

As can be seen in the following images, Yellowstone follows this design standard closely. Railings are often made of natural logs and larger, heavier barrier walls are generally constructed of stone. More recent work has utilized stone facing over concrete, as an affordable method of perpetuating historic appearances. Structural architecture is dominated by wood and stone, creating a strong sense of fit in the natural setting.

Figure 17. Roadside log barrier. The visual appearance blends into the dominant background colors.

Figure 18. Roadside stone barrier. In this case, larger grey background tones control foreground designs.

Figure 19. Typical park signage. Simple brown wood signage allows for way finding without significant degradation to the visual environment. The natural color and structural design of the signage allows this element to become a part of the visual landscape, instead of an attention grabbing, separate structure.

Figure 20. Cabins and garbage collection. Even though obviously an addition, the construction style of these small visitor cabins still allow the structures to blend with the surrounding environment.

It is the policy of the National Park Service, in general, to create a commonality amongst all of the parks within the system and this is completed through a process of "branding," much like any business. This branding affects every aspect of the National Park Service, from websites and graphic styles to landscape elements, such as buildings, walls and fences (NPS, 2012; NPS, n.d).

Other federal land management agencies have developed good examples of design guidelines applicable to this study. The Bureau of Land Management's (BLM) Visual Resource Management (VRM) program for utility implementation and design can be a useful tool for designing small scale utilidors within Upper Geyser Basin. With an emphasis on color selections and protection of viewscapes, the BLM has been successful in designing large-scale utility corridors which complement the surrounding environmental and visual aesthetic.

There are elements of the BLM VRM system that can be employed in a system designed for the National Park Service. Consideration of form, line, and color are particularly important in utility design. As small scale utilidor segments in the Old Faithful study area will be much closer to the viewing public, these design elements will need to be evaluated and employed at a more detailed level than those employed on large scale BLM infrastructure projects.

The U. S. Forest Service publication, “The Built Environment Image Guide” is also an important work for structural design on public lands. Assembled from the perspective of creating regionally appropriate fit with the natural landscape, this publication can help determine appropriate materials and design form.

Due to the very nature of utilities, design of surface utilidors could easily lead to a repetition in the small scale landscape unsuitable for an area such as the Old Faithful area. By employing different design strategies at different locations within the project site, a variety can be achieved that would promote visual stimulation instead of creating an obvious and obtrusive element in the landscape. At the same time, creation of variety will also help break the solid line of visual utility structure, thereby helping the element to blend more seamlessly into the surrounding landscape and improving the visitor visual experience (Good, 1990)

The preceding information could possibly be used to create a new, updated standard for utility infrastructure installation that is more responsive to the rapidly changing world of technology, education/knowledge improvement and ever-changing climate change. This responsiveness can help the National Park Service streamline its management efficacy and further foster hydrothermal resource protection in an age of uncertain and inconsistent budgetary cycles.

Physical Site Analysis

The region of the Old Faithful area this work concerns has a relatively flat relief, as can be seen in the contour mapping in Figure 21. Also to note is the developed site characteristics of the region of Upper Geyser Basin centered on Old Faithful, which consist of numerous buildings of varying ages, sizes and construction layouts. Table 6 provides a sampling of key buildings in Upper Geyser Basin and their respective ages.

Table 6
A Sampling of Upper Geyser Basin Building Ages.

Building	Year Constructed
Old Faithful Basin Store	1897
Old Faithful Inn	1904
Old Faithful Lodge	1920’s
Old Faithful General Store	1920’s
Snow Lodge	1999
Old Faithful Visitor Education Center	2010

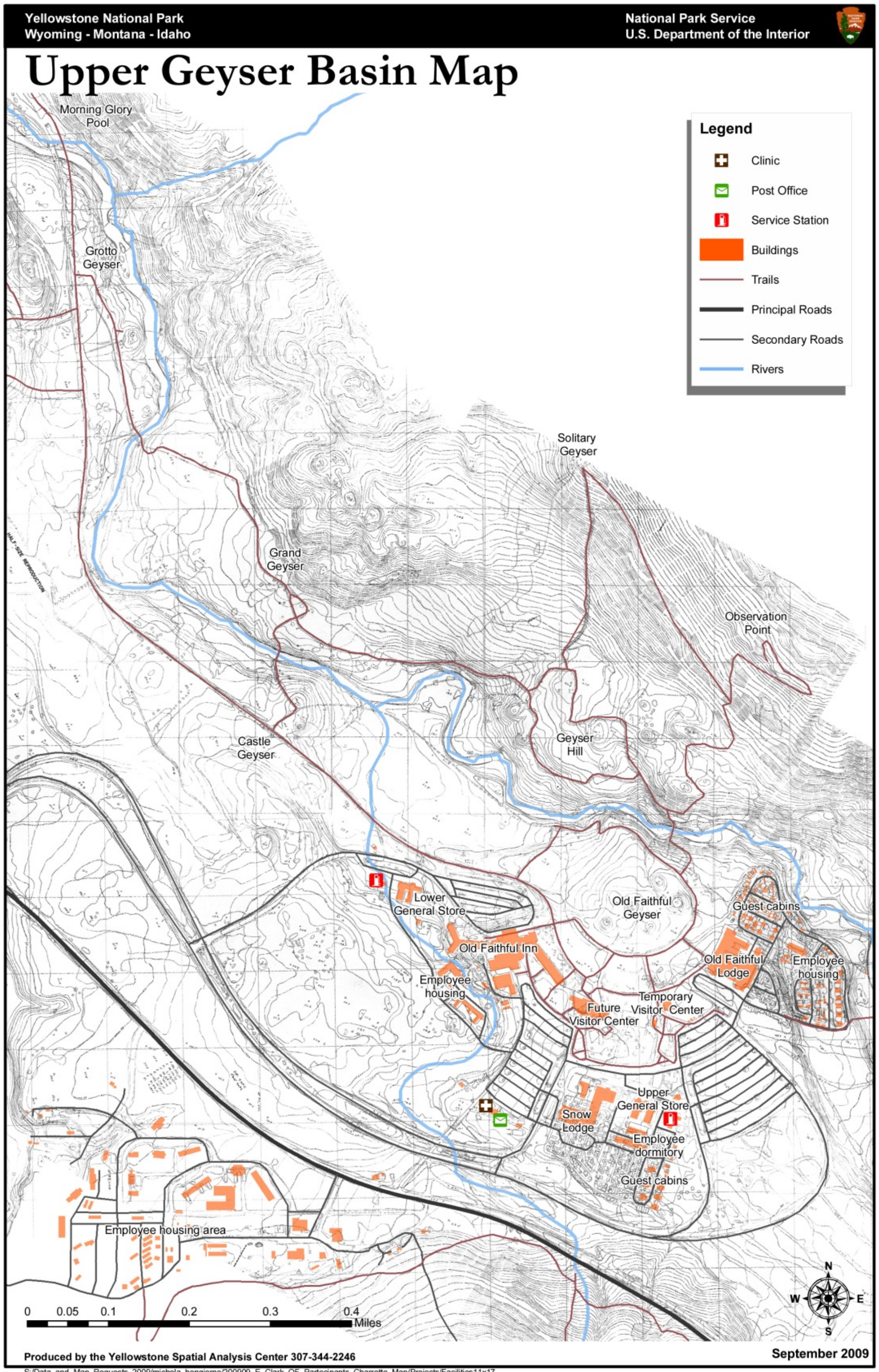


Figure 21. Upper Geyser Basin contours and site development. (Clark, 2013)

Upon first arriving at the basin, the majority of visitors find themselves located at the large parking lot found to the east of the main village complex. As can be seen in Figure 22, this large expanse of paving does little to guide the visitor to Old Faithful or the visitor center. Surface utilidor structures may be useful in connecting the parking lot lighting structures to the overall electrical grid, while also providing way finding measures for the average visitor.

Figure 22. Main parking lot on first arrival. This is the main parking lot East of the General Store. Even though the viewer is looking towards Old Faithful Geyser, it is difficult to determine direction of travel.

The flow of pedestrian traffic correlates directly with the eruption cycle of Old Faithful. Prior to an eruption, pedestrians slowly make their way to the viewing platforms, visiting the visitor center, taking pictures and generally exploring the basin region. Upon conclusion of the eruption, there is a large outflow of people leaving the basin in general. It is this large outflow that creates vehicular/pedestrian conflicts, off-route foot travel and an overall sense of disorganization in the basin.

Much of this region is devoid of pedestrian circulation control measures (i.e. rails or other sidewalk barriers). There is fair amount of “off-sidewalk” pedestrian traffic, particularly surrounding the new visitor center (Figure 23). As Old Faithful is the primary draw in this area, the pedestrian traffic is heavy. This foot traffic, multiplied countless times over numerous years is just one of the damaging effects of tourism. Sensitive soils are compacted by these uncontrolled paths and vegetation is not allowed to survive as it normally would under pristine conditions (Pickering & Hill, 2007). Partial control of this wayward pedestrian traffic could be a beneficial side effect of surface utilidors.

Figure 23. Off-route pedestrian traffic. Of the six people in this image, five are not on a sidewalk. Region: Old Faithful Visitor and Education Center.

While visible barriers may not always be desired, they are an accepted form of environmental protection utilized by the National Park Service (NPS, 1990). The primary focus of this pedestrian traffic control should and will be focused on the pathways leading from the large parking lot on the east to the areas immediately around Old Faithful and the new visitor center. It is this region that most seriously lacks proper way-finding characteristics and circulation control.

The sewage system within the UGB boundaries is currently a hybrid between traditional gravity flow and pressurized force main from a lift station. Flow is gravity controlled from individual buildings until reaching a joint lift pump station. At the lift station, the system is converted into a forced main sewer pipe, lifting the sewage to a point at which gravity can again take over ending at the treatment station just west of Highway 89.

Old Faithful Landscape Character Settings

The Old Faithful area is comprised of a number of different land use types. For the development of utilidor designs appropriate to specific settings, four distinct zones have been identified (Figure 24). These four zones (historic, tourist, parking, and natural) comprise the core of the Old Faithful area's development. They can serve as the foundation for future studies involving new development and layouts, and are intended to provide workable, yet still conceptual, alternatives to the problem of providing infrastructure in sensitive areas.

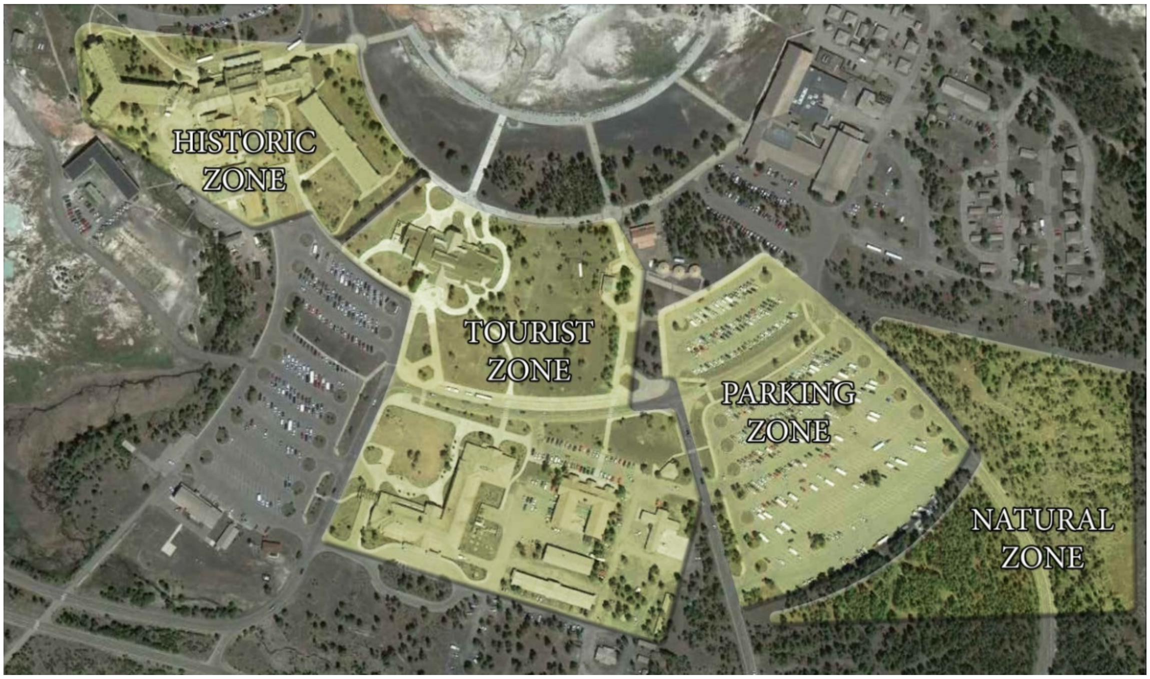


Figure 24. Old Faithful areas of focus.

The Parking Zone

The Parking Zone is characterized by expanses of flat horizontal lines, carved from the enclosing forest. The edge is defined by vertical lines of tree trunks and occasional light poles (Figure 25). Utilidor structures suitable for this zone would need to echo the dominant horizontality to blend into the surrounding environment, versus acting as an accent or focal point.

Figure 25. Parking lot horizontal and vertical design influence. The predominant horizontality of the zone is an important influence in informing appropriate utilidor design.

Colors in this zone overwhelmingly consist of greys (paved surfaces) and greens (outlying vegetation). Neutral earth tones are suitable for this zone (Figure 26), with a tendency to lean towards colors blending seamlessly into the largely paved surfaces. This color tendency will lead to materials consisting of concrete and stone. Where Parking Zone utilidors exist along the forested boundaries, selection can be expanded to include warmer brown tones, and material options expanded to include wood.

Figure 26. parking lot color dominance. Predominately grey and green, cold, hard structures will blend in best.

The Tourist Zone

This zone, centrally located within the Old Faithful area, encompasses the new visitor center and buildings surrounding the Upper General Store and is the focus of the vast majority of area visitation. With a variety of architectural ages and styles, this zone is therefore the most diverse in terms of utilidor options and possibilities.

The two locations within this zone used for the landscape character setting study are the Upper General Store and the new Old Faithful Visitor Education Center. The store, built in 1929, is representative of the rustic style of architecture (log, wood, and stone construction) typical of the period. It is listed on the National Register of Historic Places as a contributing structure to the Old Faithful Historic District. The Old Faithful Visitor Education Center, built in 2010, is a blend of contemporary forms and materials that reference older structures within the historic district.

Visual “lines” in this zone are much more equally distributed between the vertical and horizontal (Figures 27 and 28). As an overall generalization, utilidors taking a more vertical appearance in the landscape would be appropriate, as their presence would be much more compatible with the surrounding landscapes.

Figure 27. General Store horizontal and vertical design influence. This region has a much more blended mix of horizontal and vertical lines. Horizontal surface utilidor runs would blend well.

Figure 28. Visitor center horizontal and vertical design influence. The newest building in Upper Geyser Basin uses long-sloping roof lines to balance the vertical and horizontal visual aspects of this area, blending into the landscape and the distant hills behind Old Faithful Geyser.

Neutral colors are accented with stone-clad walls and pillars, and the building accents hint of the natural environment. Neutral yet cool earth tone colors are again the dominant theme in this zone, with a much larger percentage of tans, browns, and greens creating the color palette (Figures 29, 30, and 31).

Also important in this zone are the rough textures of stone, complimented with the textures of rustic wood beam detailing. These coarser textures are gently offset by that of the siliceous sinter-containing ground plane, a unique – almost gravel-like – texture surface.

Utilidors in this zone should be subsidiary to building architecture, while echoing and supporting the form, line, color, and texture of existing structures. Utilidor walls with architectural detailing would avoid monotony and would be suitable for this zone.

Figure 29. General Store color palette. While still heavily influenced by grey-toned paved surfaces, the region surrounding the General Store more evenly distributes greens and browns in the visual palette.

Figure 30. Visitor center (front) color palette. The Front of the new visitor center is heavily influenced by the textures and colors of the architecture of older structures in the Old Faithful Historic District. Stone, vegetation and wood are strong elements.

Figure 31. Visitor center (back) color palette. The back side of the visitor center, facing Old Faithful Geyser, continues the basin-wide theme of grey-toned paved surfaces and sinter deposits with accents of stone, wood and vegetation.

The Historic Zone

The Historic Zone centers around one of the oldest built elements in Yellowstone, the Old Faithful Inn. This "zone," which is almost entirely comprised of the structure itself, plays important visual roles in the basin from both the front and rear aspects. The pure size of this building creates numerous vertical and horizontal lines contained almost entirely within its structure, and it strongly dominates the surrounding landscape (Figures 32 and 33).

The color palette of the Historic Zone is heavily dominated by the architecture of the Inn, one of the progenitors of national park rustic architecture and design. Brown wood tones and textures, accented with the grey tones and textures of typical park stonework, provide a visual foundation for other regions within the Old Faithful area. The lighter, softer greens of vegetation act as simple accents, without detracting from the history and stature of the architecture (Figures 34 and 35).

Addition of surface utilidors in this zone must be mindful of the important historic architecture of the building. If possible, utilidors here must not become an individual visual element in the landscape. This is not a location in which to focus attention and will be most suitable for “hidden” technologies, if possible.

Figure 32. Old Faithful Inn (rear) horizontal and vertical design influence. The rear of the Old Faithful Inn, while providing an imposing vertical centerpiece, also uses numerous horizontal lines to create a unique visual element within the basin.

Figure 33. Old Faithful Inn (front) horizontal and vertical design influence. The front of Old Faithful Inn is an impressive display of vertical, yet also horizontal, presence in this otherwise level landscape, putting its form on par with that of the basin-surrounding hillsides.

Figure 34. Old Faithful Inn (rear) color palette. The rear of the Inn is also heavily dominated by the natural earth tones, as is the front.

Figure 35. Old Faithful Inn (front) color palette. As can be seen here, natural tones of greens and browns dominate the visual landscape in front of Old Faithful Inn.

The Natural Zone

The Natural Zone, located to the east of the main Old Faithful area parking lot, has been identified to provide an idea of potential surface utilidors appearance when located in less developed portions of the park. This zone is dominated by the vertical elements of trees and horizontality is at a minimum in this zone (Figure 36).

Figure 36. Natural forest horizontal and vertical design influence. The verticality of the Natural Zone requires the judicious use of horizontally structured surface utility corridors.

Colors in this zone are naturally dominated by natural earth tones, with the cool greys of paved surfaces at a minimum, and the textures of wood and sinter occupying a high percentage of the visual landscape (Figure 37).

Compatible utilidors in this region would include those along a more unnoticed or "invisible" design solution. Careful attention must be paid to the texture and colors of the surrounding landscape in order to blend utilidors seamlessly into the landscape.

Figure 37. Natural forest color palette. The dominant greens and greys of the Natural Zone color palette will play a significant role in the design of surface utilidors in natural areas.

As a surface visual element in a predominantly vertical space, these utilidors have the ability to serve in both a visual and functional capacity. Their long runs through the forest have the capability of providing two important components of landscape architecture; that of extending a visual sight lines and/or providing a sense of security through a more enclosed space. By carefully determining materials, their visual impact can be lessened and appropriately placed within the landscape. With an appropriate routing plan, curving or otherwise altering the run of the corridor, the perceived length of the utilidor run can be minimized.

As an unseen or “invisible” solution, the utilidor would further enhance the genus loci of the surrounding forest, a reason so many come to visit places such as Yellowstone in the first place. In this solution neither color, texture nor line dominance will be determining factors.

Current Infrastructure Requirements

Following (Table 7) is a listing of the wet infrastructure requirements for the buildings outlined above. While the requisite electrical and communication lines are unknown at this point, their relatively small size allows for flexibility in the ultimate design and for assumptions to be made in the prototypes presented here.

Table 7
Wet Utility Requirements for Buildings in Scope of Work

Old Faithful Inn
Water: two 3” fire protection lines, three 4” fire protection lines, two 6” fire protection lines, two 6” domestic lines, two 4” domestic lines
Sewer: 8” line coming out of entire area (Inn, dorm behind it)

Old Faithful Visitor Education Center
Water: 4” line coming in, 6” fire protection line coming in
Sewer: 8” line going out

Parking Lot – to – Old Faithful Connection Bathrooms
Water: Unknown (1.5” assumed)
Sewer: Unknown (Two 4” combining to One 8” assumed)

Upper General Store
Water: one 2” line for fire protection, one line of unknown size for domestic water
Sewer: 6” line coming out

Specific Design Issues and Opportunities

It is not the intent of this work to provide solutions for large-scale utilidor design. It is, however, intended to provide practical solutions for site-specific applications of needed utility systems and their routing. The design applications and recommendations presented by the prototypes are an attempt to utilize as much of the existing system as possible, with minimal disturbance.

Due to the increased expense of creating surface utilidor systems, even new construction should continue to employ traditional methods of utility transport, i.e. trench-and-bury, where appropriate. Small scale utilidors are not capable of containing the large elements needed in larger scale projects. They are simply a component of the larger planning structure.

To use the Old Faithful area, here, as a purely conceptual example, Figure 38 shows the approximate routing of existing main utilities. The existing utility corridor (blue) traverses the entire developed Old Faithful area, carrying sewer, water and, possibly, electrical lines. While under normal conditions this corridor would be required to extend to every building, toilet and light pole in the area, under a condition of surface utilidors this buried corridor is minimized in scope. Instead, individual, or small groups, of buildings are connected to this line through the means of a surface system of utility corridors (red).

By utilizing both surface utilidors *and* conventional buried utility conveyance, costs can be better controlled, both through ease of construction and reduction in length of the more expensive pumping systems (sewage force mains). Utilizing buried systems or “hybridized” utilidors can help provide occasional breaks in above-surface lines, create opportunities for crossings, and provide visual breaks in an otherwise strong horizontal line. Utilizing the gravity-controlled main line sewer system found in the buried corridor can also help in the reduction of costs and complexities of creating numerous force main mini-systems.

Here in the Old Faithful area, utilizing existing main lines when possible is also an important component of preventing unnecessary ecological damage to the subsurface hydrothermal systems. The point is to reduce, or eliminate, the amount of trenching and ground vibration and to provide replacement alternatives for when the inevitable failure of buried systems occurs or new construction is required.

Figure 38. Approximate routing of existing utilities and conceptual utilidors. Small scale utilidors should be kept short to minimize expensive components and provide much need design options.

Utilidor Design Alternatives

Barrier

In any type of sewer and water supply planning, cross contamination is a concern. When placing both water and sewer lines in close proximity, special care must be taken to create sealed compartments capable of mitigating this risk.

Drainage in the event of leakage or pipe rupturing is crucial to the design of this barrier-style utilidor. As they are located in a sealed "tube," so to speak, liquids must be able to exit the chamber to avoid cross contamination potential and increase response times for the necessary repairs. These same drainage holes in the "skin" of the utilidor will also help prevent and mitigate possibly damaging effects of condensation within the utilidor system.

Precedence for small-sized utilidors does exist. However, these pre-manufactured systems are designed and constructed in such a way as to achieve the goal of full-burial. Their sizes however are evidence of the ability to contain utility systems within a confined space. Advanced Concrete Products, Inc., of Highland, Michigan, offers a multitude of design options based on project requirements. These precast concrete structures are intended to be modular, assembled in place once arriving on the jobsite. It is feasible to plan a cast-in-place structure of the same magnitudes, if a modular system is not desired. Table 8 lists the smaller of their product line offerings.

Table 8
Pre-Manufactured Utilidor Precedence. Product line of small-size utilidor systems offered by Advanced Concrete Products, Inc. of Highland, Michigan (Advanced Concrete Products, 2014)

Interior Size (HxW)	Wall Thickness	Reinforced?
22" x 28"	~4 inches	Yes
30" x 36"	4-6", tapered	Yes
36' x 36"	4-6", tapered	Yes
36" x 42"	4-6", tapered	Yes
36" x 48"	6-8", tapered	Yes
36" x 60"	4-6", tapered	Yes

Figure 39 details the attributes and provides a general layout example of one example of a barrier-style utilidor. Note how the construction recommends above-natural grade construction, utilizing tapering fill on the landscape side and a flexible attachment to a new or existing sidewalk. This flexible attachment zone is primarily intended to allow for movement in the event of winter frost heave, but the enlarged footing, extending below

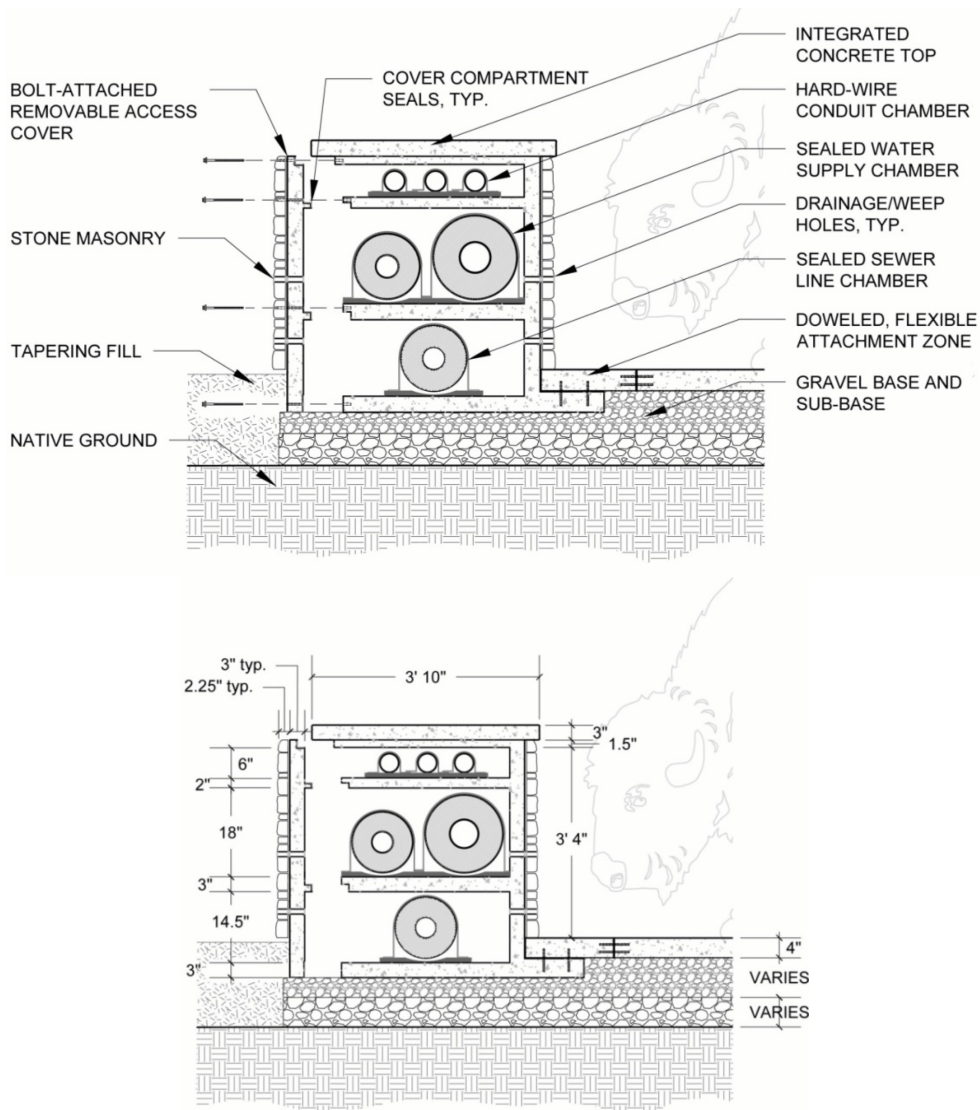


Figure 39. Cross-sectional detail of the barrier utilidor. Pipe sizes and insulation are detailed assuming the upper end of design requirements to ensure size compatibility. Selection of different materials could potentially reduce pipe and insulation sizes.

the sidewalk also allows for added rigidity in the event large wildlife (bison) decide to rub or push against the structure. A removable side panel is crucial to the installation, maintenance and repair of the system. This style of barrier creates an aesthetic and useful tool in controlling unwanted, off-path circulation patterns while maintaining the aesthetic design style of the associated building architecture.

Seat Wall

Seat Wall utilidors are generally only suitable for very short run lengths and small amounts of enclosed utility infrastructures. Incorporation of these types of utilidors would be ideal for areas experiencing high levels of visitor traffic, where circulation needs to be controlled while still blended into the surrounding visual environment.

Although constructed in a similar fashion as that of the Barrier, their usage is limited due to the visual appearance of the structure itself, as long runs of seat wall would be visually distracting. While the styles and appearance of Seat Wall utilidors can vary depending on built location, it would be difficult to implement these styles due to the requisite breaks in the visual design.

Figure 40 details the Seat Wall and its necessary attributes. This style of utilidor is similar in overall idea to that of the Barrier. The enlarged footprint again utilizes a flexible joint design, while also adding rigid security to the damaging effects of large wildlife. Vents in the sidewalls of both the Seat Wall and the Barrier are screened to prevent small animal habitation within the utilidor structure.

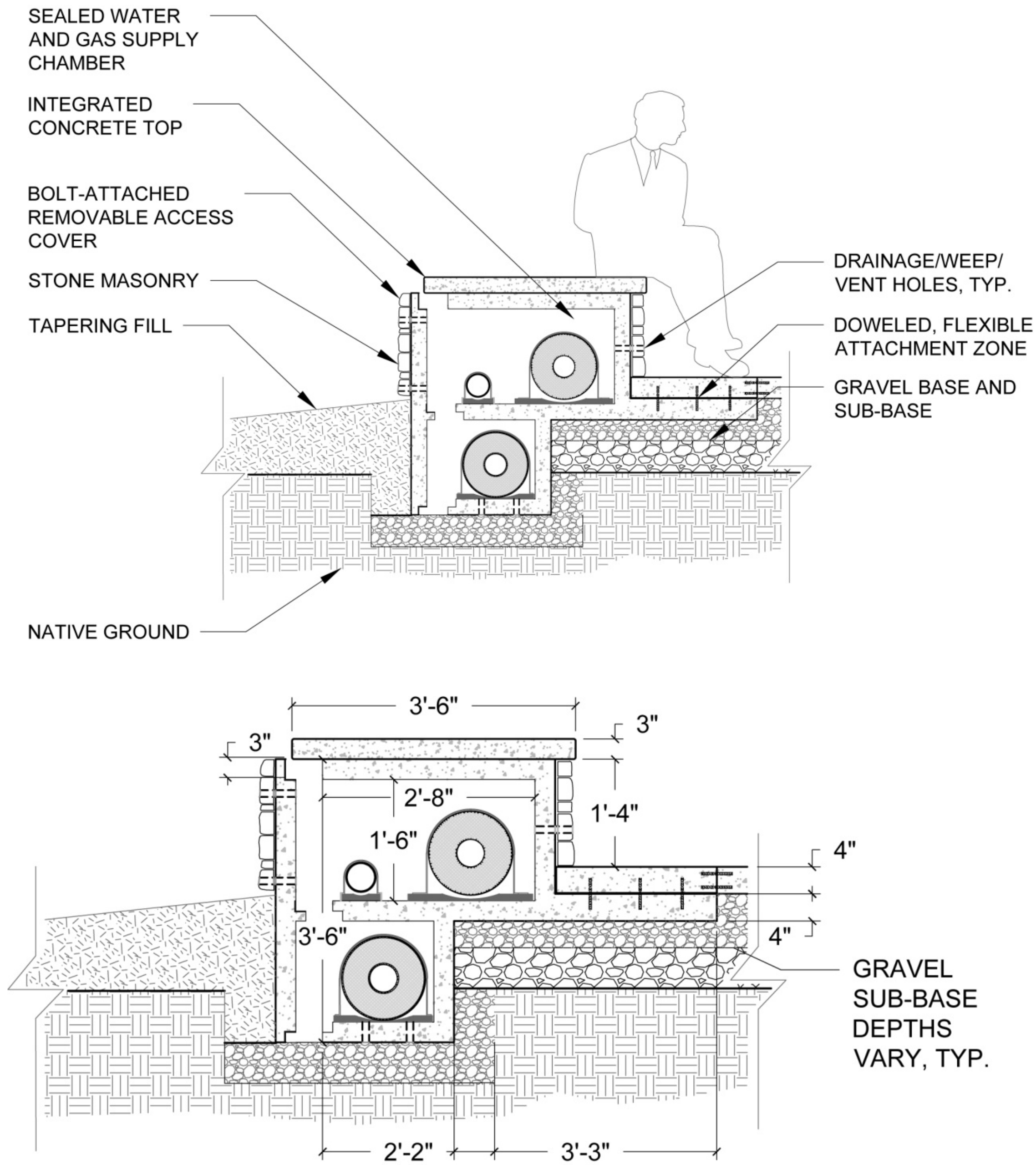


Figure 40. Cross-sectional detail of the seat wall utilidor. In this detail section, notice the lack of electrical service. It is not recommended to place electrical lines within the same service corridor as gas lines. Electrical line conduits could replace the gas line space in the event gas is not needed in the utility conveyance plan. The Seat Wall utilidor is ideal for smaller utility requirements and very short runs.

The same precedence found for the Barrier utilidor is applicable to the Seat Wall design, and removable side panels are an important element of this design as well, as installation, maintenance and replacement of internal components is required.

Large Incorporated Vault

Vault-style utilidors share much with their buried utilidor cousins, as both are subsurface corridors, hidden from view. While not buried as deeply as typical utility infrastructure, if at all, the vault utilidor can be incorporated into surface elements, while still being able to have their construction above native soil levels. Uses for this type of utilidor would include areas necessitating no visual impact, or where the placement of a surface structure would cause conflicts with directional travel. Placement of a Large Vault may include locations such as integration into a sidewalk or street crossing.

Capable of handling numerous utility lines, the Large Vault may also inhabit the very top layers of the native soil profile. While obviously not ideal within the confines of the Old Faithful area, suitability must be looked upon as a basis of reducing trenching impacts. While some ground may be disturbed, much more of the deeper profile can be left intact. The Large Vault could, at times, be considered as a compromise between development and ecosystem protection.

Large Vault utilidors can be readily purchased from a manufacturer such as Advanced Concrete Products, Inc. as a modular system, or they can be designed and poured on site, depending on actual site conditions (slopes, soils, applications, etc.). As can be seen in Figure 41, the general nature of this Large Vault could be capable of numerous designs, increasing installation flexibility based on requisite building infrastructure components.

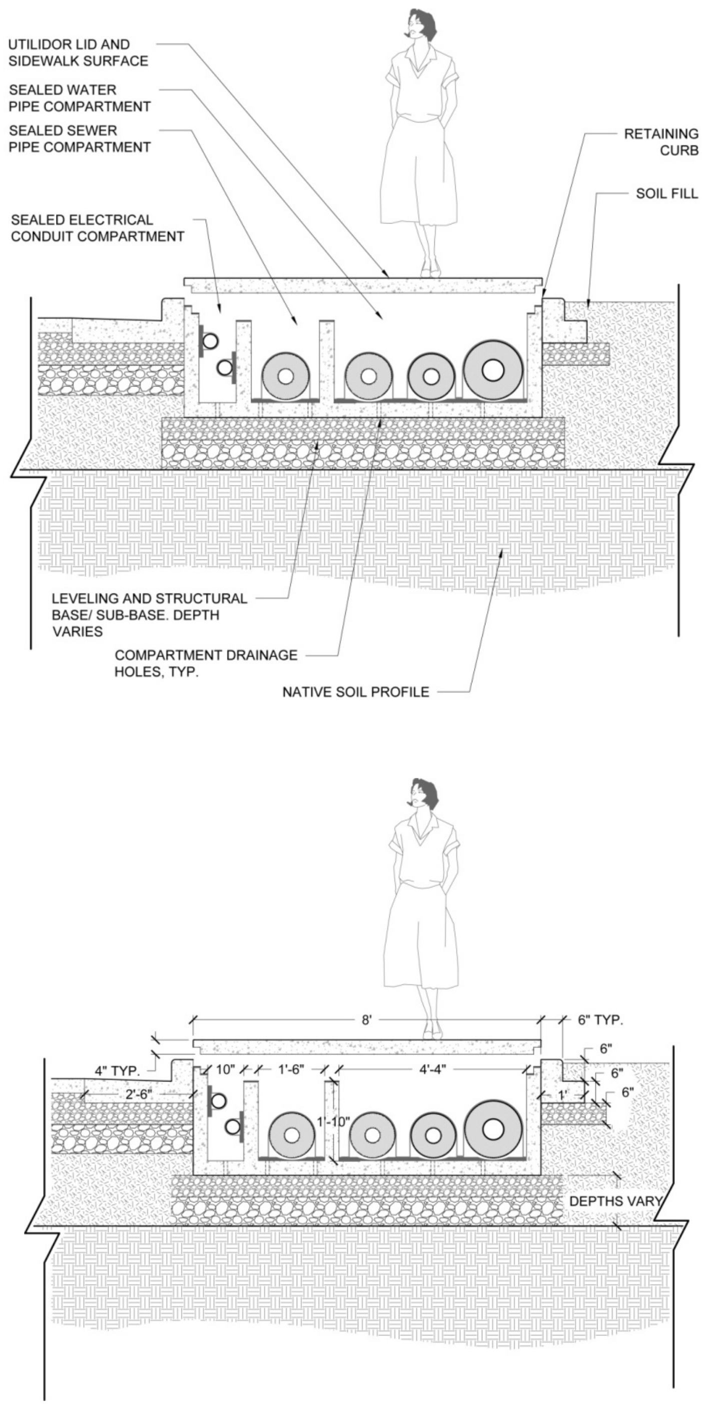


Figure 41. Cross-sectional detail of the large vault utilidor.

Advantages of the Large Vault include the ability to completely “hide” the internal utility structures, reduced structure/wildlife conflict, a significantly reduced amount of excavation, an ability to incorporate the structure into above-natural-grade constructions, decreased installation labor costs if utilizing modular components, and an increased ease of building or lift pump points of connection. Disadvantages include an increase in difficulty when it comes to maintaining or replacing internal components as compared to full-surface systems, and the potential to still have to engage in a certain amount of excavation for system installation.

Small Incorporated Vault

Utilidors which are smaller in scope and stature than those of the Large Vaults are a suitable alternative for utility applications requiring less infrastructure components. By using a Small Vault to carry, for instance, a single utility line, project impacts to environmental and economic considerations can be greatly reduced. Vaults of this size are also available on a mass production basis. Advanced Concrete Products, Inc. is but one of many companies producing this size vault, and again, if conditions warrant, on-site construction is possible for increased flexibility in design considerations. See Figure 42 for technical details of this smaller vault.

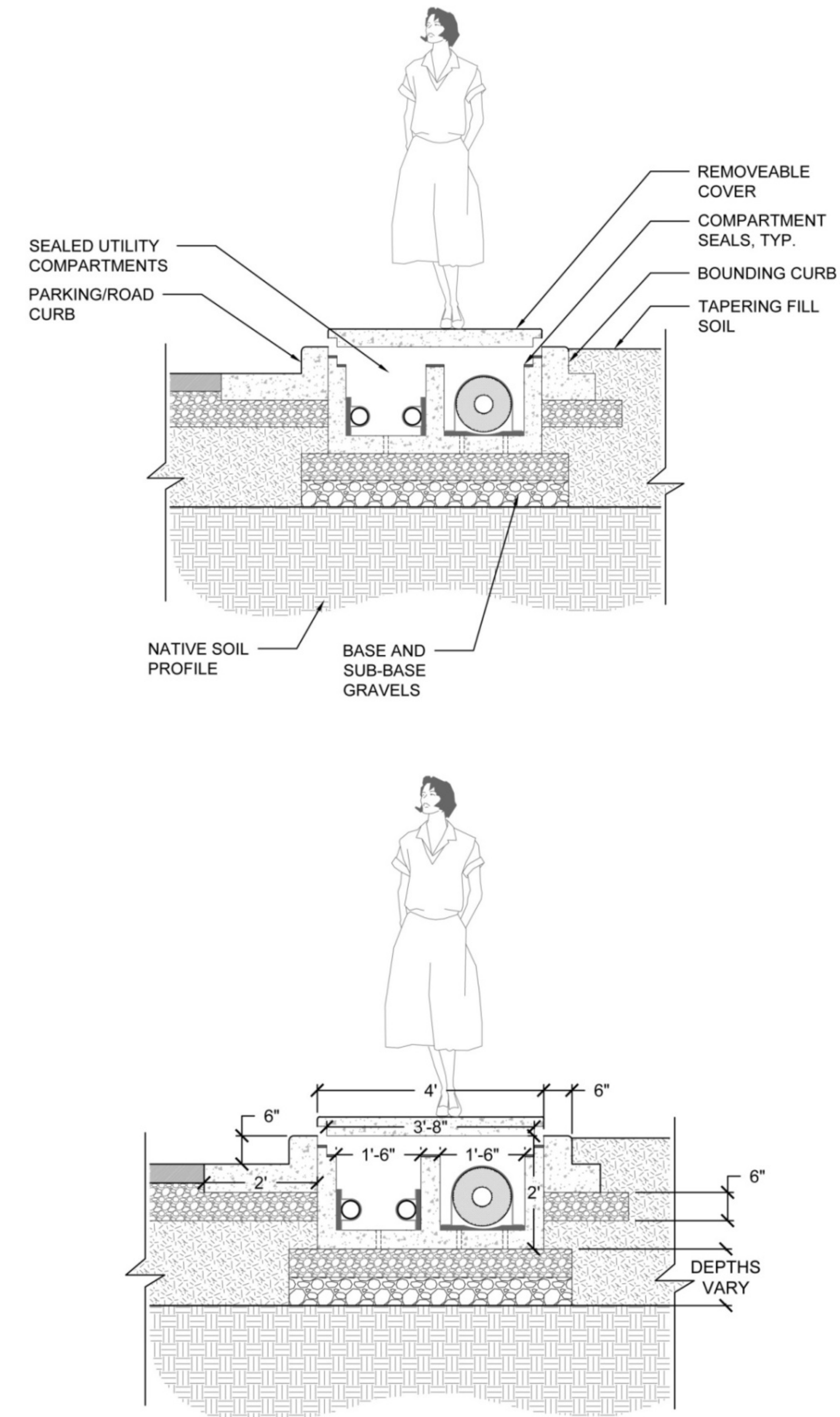


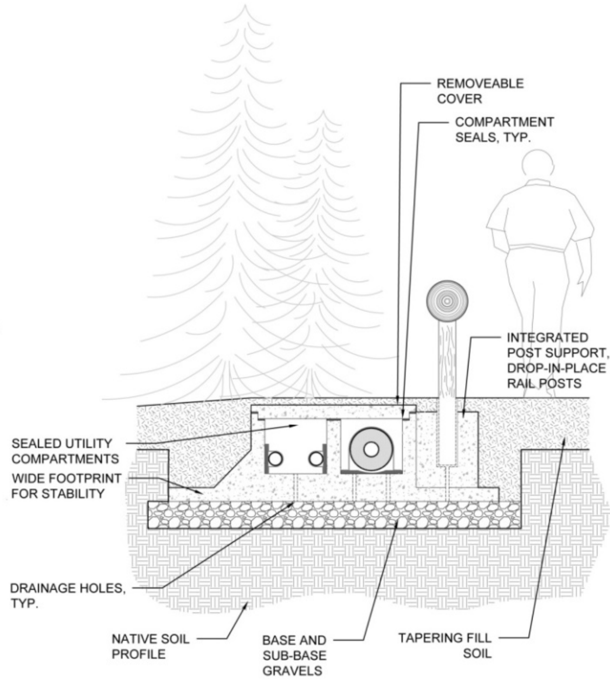
Figure 42. Cross-sectional detail of the small vault utilidor.

Both the Small and Large Vaults could be considered as hybrid utilidor systems. While not technically surface systems, their placement just below developed structures such as sidewalk or roadways, or within just the very surface layer of native ground, allows for development of utilities without the full environmental impact of traditional utility trenches.

Rail Barrier

The Rail-Barrier utilidor is a combination between a typical log rail barrier and vault utilidor. Their surface appearance is reflective of the numerous low, log railings found throughout the park. The usefulness of this utilidor style comes in its ability to seamlessly blend into the existing landscape, particularly due to the fact that this is an established and well-accepted design detail utilized, not only in Yellowstone, but throughout the national park system. While the unexposed portions of the utilidor may employ the highest and newest of vault technologies, the visible surface elements of its construction are able to maintain the rustic, simple aesthetic of the log barrier while creating a system easily maintained by park staff.

While not a true “surface” utilidor, like its vault cousins, it again has the ability to significantly reduce, and possibly eliminate, the requisite trenching for building scale development. Figure 43 shows the construction details of this style of utilidor.



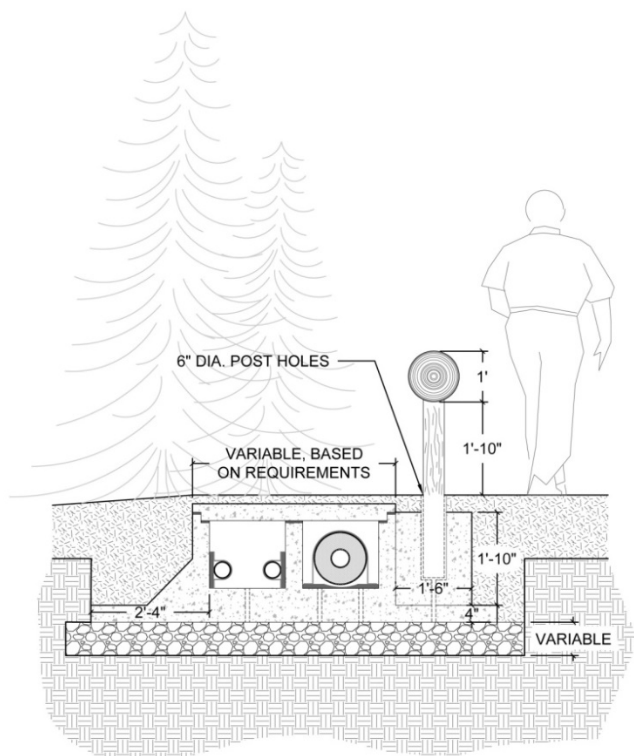


Figure 43. Cross-sectional detail of the rail barrier utilidor. Take special note of the structure-to ground connections, which provide the structural integrity of a design of this style.

Of important note with this alternative is the necessity of engineering a secure structure-to ground connection. As this style of railing is generally very low to the ground, it is assumed wildlife conflicts and associated damage would be generally low. Still, considering the contents found within, special attention needs to be paid to this design. Large foot prints extending beyond the component-carrying structure may be required to ensure stability without having to extend construction too far into the native soil profile.

Foundation Extension

The Foundation Extension is an utilidor for application where large sizes or numbers of utility lines coming together at a single, or closely spaced, point of connection with a building. This extension is an idea which can create a “bridge” between a necessary point of connection and a visually appropriate utilidor system. This system is intended to blend into the existing structures foundation, hugging the footprint of the structure and blending into the existing architecture. It is intended to become a separated architectural extension of the building, but not be placed below existing structural components.

The purpose of a design such as this is to create a corridor which can be used in historically significant architecture, where the placement and construction of the utilidor will not damage either surface features or building structural elements. This idea would be used primarily in the event utility line failure necessitated replacement and would reduce damage to buildings otherwise necessitated to cut into the existing structure.

Care must be taken to create a structure which is freestanding from the historic architecture in question and which will not ultimately lead to the potential for visual conflict with iconic structures. One possible design solution for this idea is detailed in Figure 44, although finalized Foundation Extension designs could potentially vary widely depending on site architectural requirements.

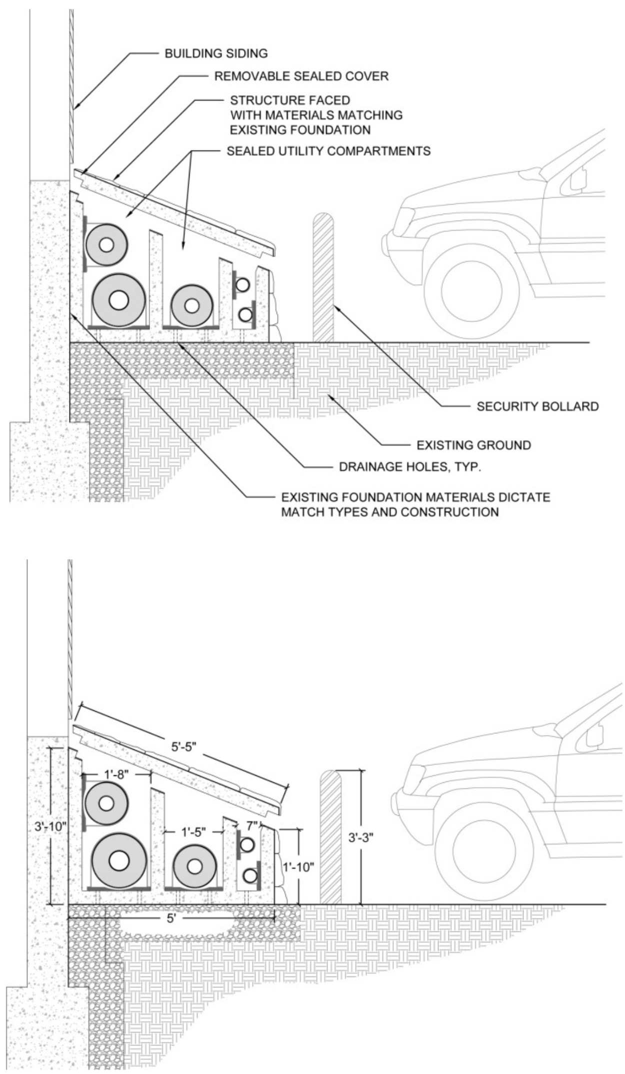
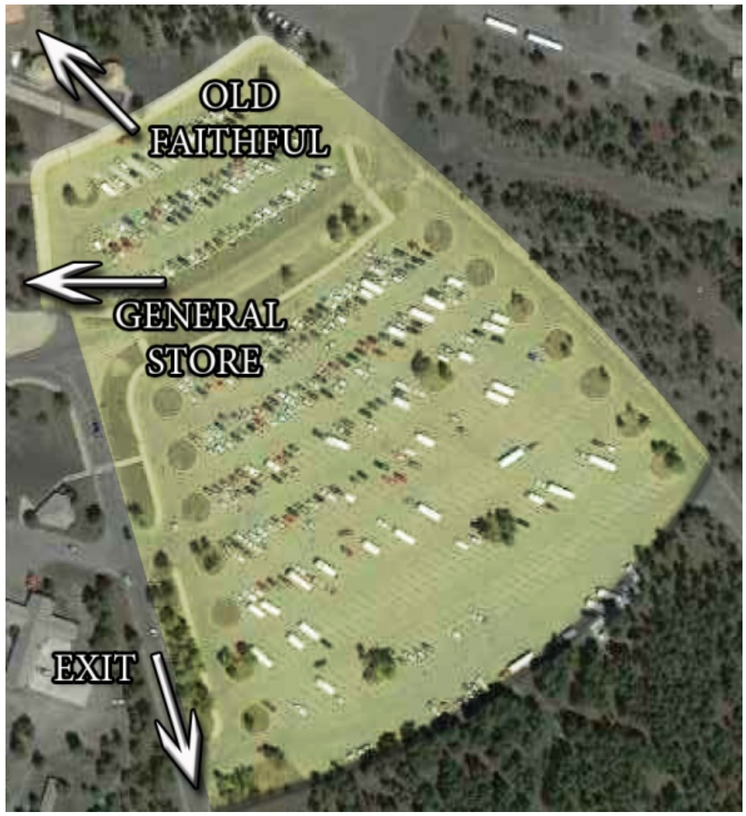


Figure 44. Cross-sectional detail of the foundation extension utilidor . Final design of a foundation extension is dependent on building materials. Full surface placement or partial bury are options for this utilidor design. Full surface placement is shown.

Design Solutions by Zone

Parking Lot Zone Application



The Parking Lot zones are ideal for utilidors that blend seamlessly into the landscape. Low heights or hidden profiles would be most ideal for this zone, as these locations are not focal points within the basin. Pedestrian-utility conflicts need to be kept to a minimum, with the exception being in locations where the utilidor may also act as a pedestrian control or way-finding feature.

For the majority of this zone, vault style utilidors would be most appropriate, as they are incorporated into the ground plane. If included in a sidewalk structure, these vaults can also help to guide and steer pedestrians from their vehicles to key destinations within the Old Faithful area. The edges of this zone may be more appropriately treated

Figure 45. Abstract sidewalk utilizing vault image. Composite image showing the physical factors (vehicles, pedestrians, hardscapes and nature) involved in the design of parking lots utilizing a large vault style utilidor.

Figure 46. Parking lot boundary utilizing barriers. The Parking Lot zone is suitable for primarily vault utilidors, unless steering pedestrian traffic through the use of Barrier-style structures. This image shows the appearance utilizing edge barriers and sidewalks in a realistic placement.

Currently, the Parking Lot zones have little in the way of pedestrian or traffic directing capabilities. By subtly adding sidewalks and barriers to this zone, way-finding can be improved and pedestrian traffic, hopefully, directed in a more efficient manner. with Barrier or Rail Barrier utilidors in a more controlled attempt to direct the flow of pedestrian traffic onto the paved walking surfaces (Figure 46).

There are several light poles spread throughout the main parking lot east of the Tourist Zone. By arranging these light locations to coincide with the addition of sidewalks crossing this zone, it would be possible to organize the parking lots in such a way as to utilize Small Vault utilidors containing only electrical lines. By accomplishing this redesign, two important elements of park management could be achieved: creating a more organized system of way finding and supplying the necessary lighting elements required for the health, safety and welfare of tourists.

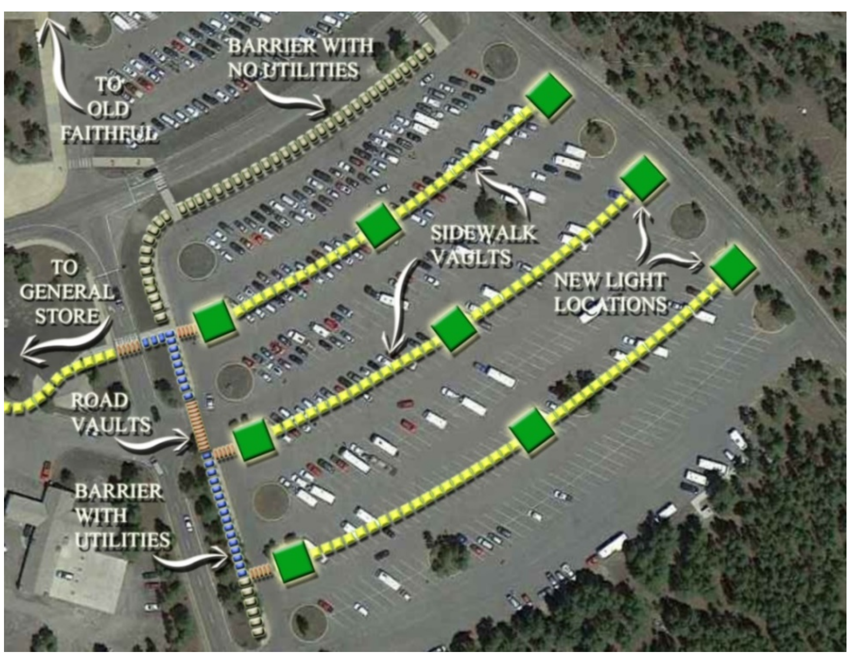


Figure 47. Utilidor routing and types

The vault and internal barrier spaces in this zone do not need to be as large in size or scope. Unless acting as a pass-through for utilities from other zones and regions, the only utilities required for this zone include electrical lines for the lights illuminating the lots. Figure 47 (above) indicates the routing and types of Parking Zone utilidors, while Figures 48 and 49 depict the connection transitions between the different utilidor styles.

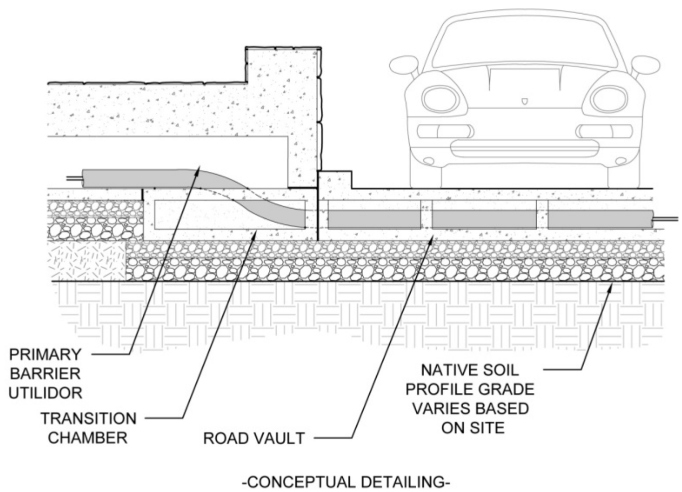


Figure 48. Barrier to road vault connection utilizing transition chambers. This detail shows the lateral transition from a surface utilidors to a subsurface small-scale utilidor.

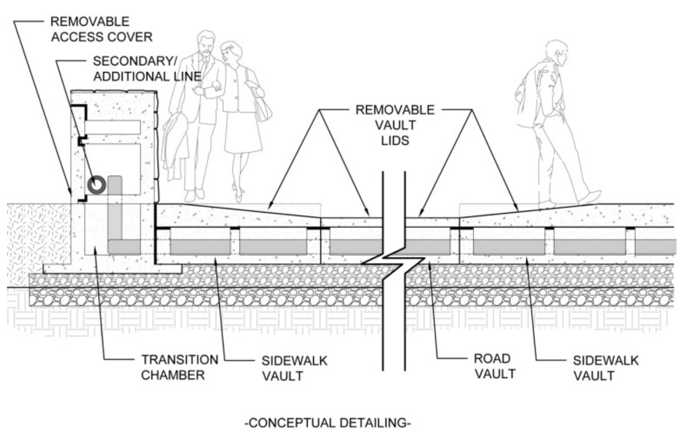


Figure 49. Multiple crossings vault utilization. The information above shows the transition from north-south corridor orientation to east-west corridor orientation utilizing barriers and vaults while crossing both vehicle and pedestrian pathways.

Tourist Zone Application

Key features in the Tourist Zone of the Old Faithful area which determine utilidor placement involve controlling wayward pedestrian circulation in an attempt to preserve sensitive soils and plant communities, short run lengths to prevent "trapping" of wildlife which could increase wildlife/human conflicts, and maintaining current design standards and guidelines. As the Old Faithful Visitor Center is the primary building of focus within the Tourist Zone, with its proximity to Old Faithful Geyser generating the greatest amount of concentrated impact in the area, application of Barrier utilidors at this location seems to be most appropriate.

The Barrier utilidors will provide conduits capable of carrying large amounts of utility elements in a confined and concealed space, easily repairable with little ground disturbing impact. Aesthetically, barrier utilidors would reflect materials already existing within the park, creating stone walls that are both functional and aesthetically pleasing. The new visitor center has included stone masonry in its architecture and repeating this same visual element in adjacent utilidor design will help create visual continuity.

Figure 50. Abstract barrier utilidor image. Composite image showing the ability of a Barrier Rail style utilidor to blend with existing structures and visual landscapes.

Wet utilities supporting this building include one four inch culinary water pipe, one six inch fire protection pipe and one 8 inch sewer pipe removing waste from the structure (M. Nelson, personal correspondence, February 11, 2014). Ample space exists within the utilidor for wired utilities as their space requirements are much less than that of water and sewer lines.

Connection points for this utilidor would include locations found at the northwest corner of the visitor center, within the existing fenced enclosure, and at the edge of the driveway, where the sidewalk is met. Figure 51 shows these locations.

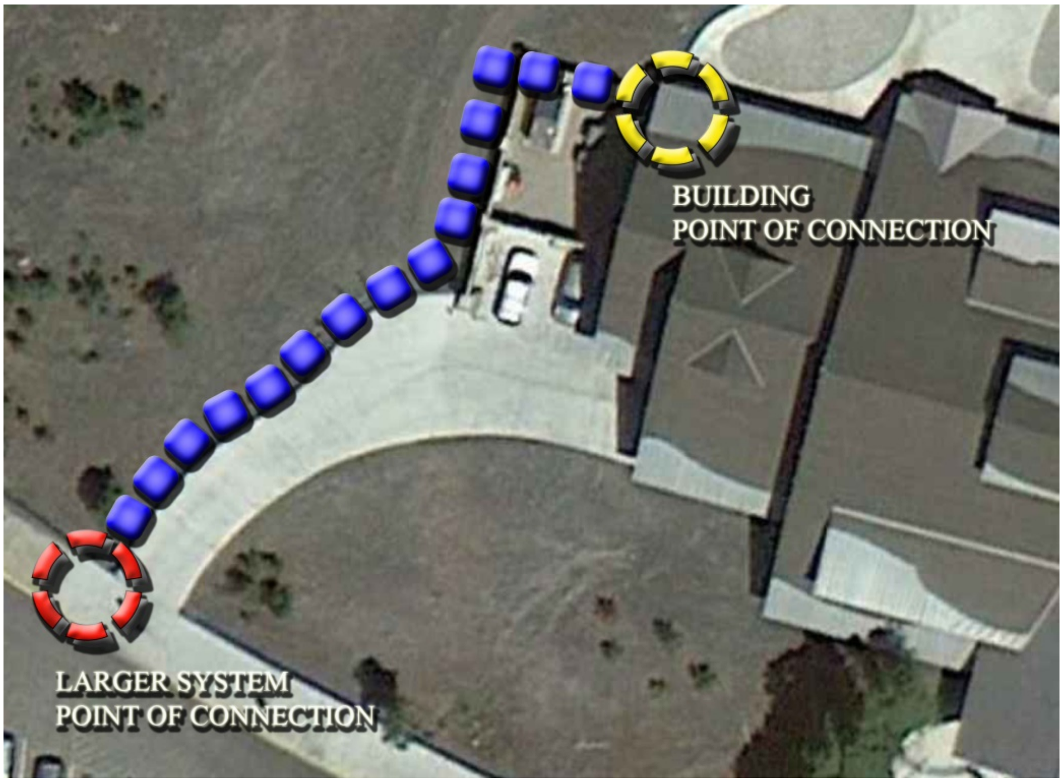


Figure 51. Visitor center West utilidor route and points of connections.

As can be seen in Figure 52, installation of a Barrier utilidor can be become an aesthetic extension of the building structure, in this case connecting the west side of the new visitor center with the larger utility infrastructure system. The color and texture of the stone is a match with the existing architecture, and the low profile of the structure provides a visual landscape feature, without becoming a dominant element.

Figure 52. Barrier utilidor connecting the visitor center to main lines. Notice the attention paid to the elements of scale, color and lines within the environment, and the role this utilidor plays in acting as an extension of the building structure. Simultaneously, this utilidor restricts some off-path pedestrian traffic while not inhibiting wildlife movement.

This specific utilidor, 180 feet in length, could be built almost entirely without the disturbance of the natural grade, save for the connection point to the building (Figures 53 and 54) and the larger infrastructure system (Figure 55). For this single utilidor, an estimated 600 cubic yards of soil could remain undisturbed, based on an assumed utility trench 15 feet deep and 6 feet wide.

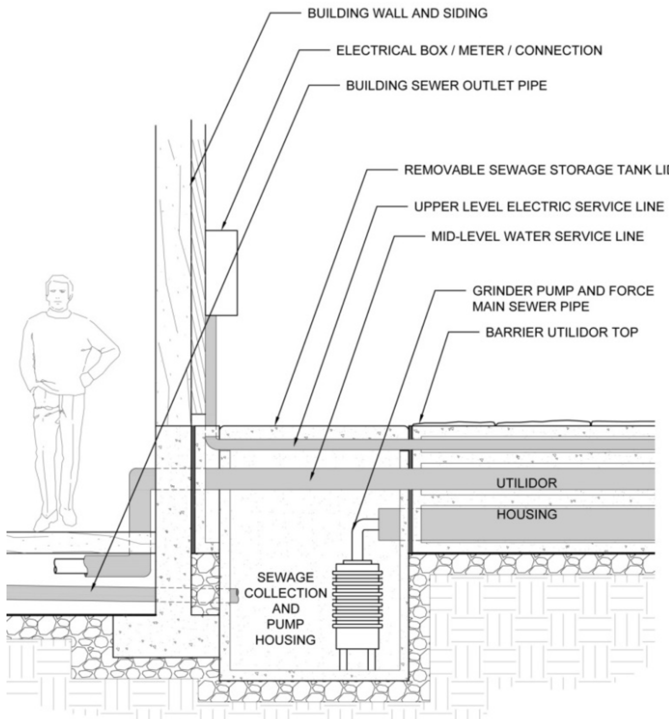


Figure 53. Building connection section detail. Section view of the connection of the barrier utilidor to the existing structure and placement of a grinder pump force main sewer system.

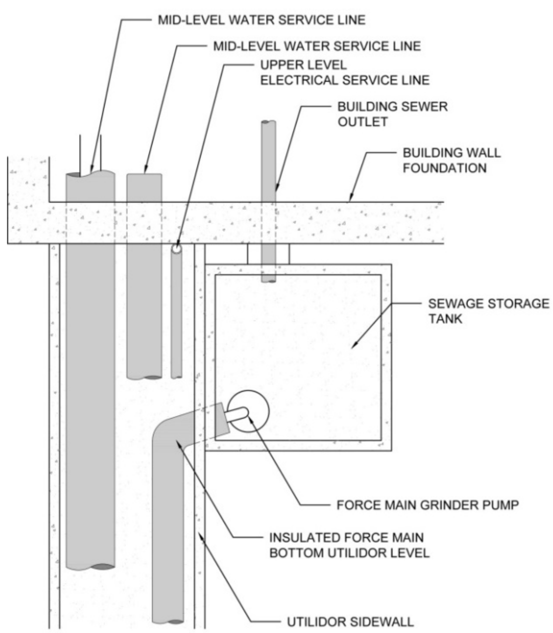


Figure 54. Building connection plan detail. Plan view of the connection of the barrier utilidor to the existing structure.

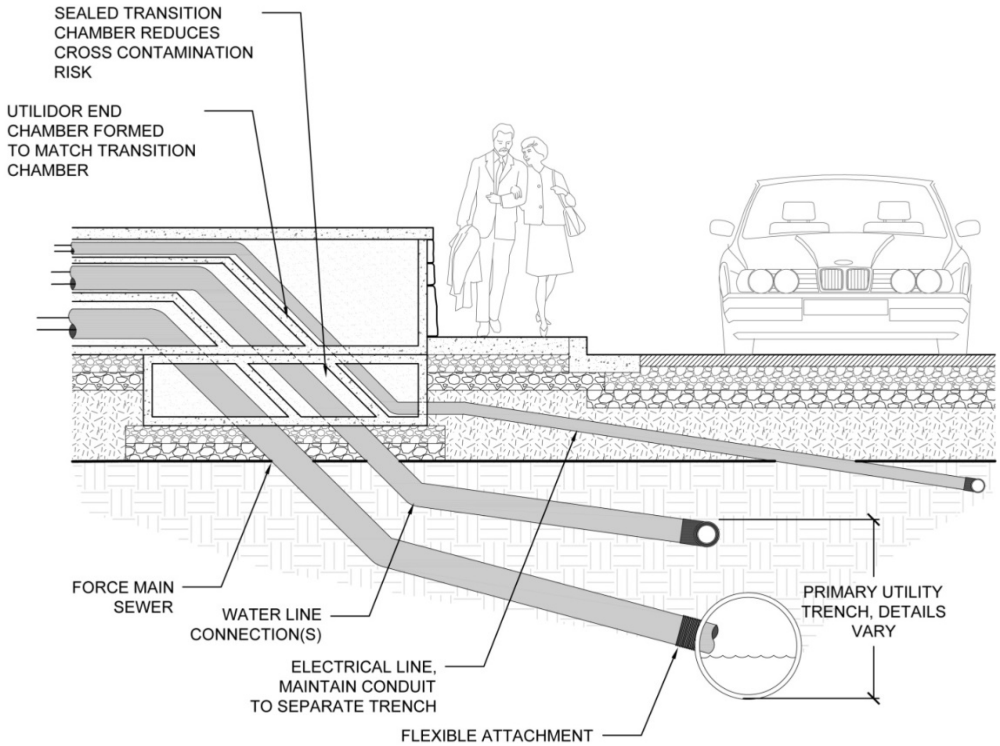


Figure 55. Barrier connection to main infrastructure system. Again utilizing a transition chamber, the barrier utilidor can create connections with minimal to no soil disturbance. For barrier to vault connections, refer back to Figures 48 and 49 on page 96.

Connecting the Upper General Store to the primary infrastructure system is a little more complicated, as there are numerous points of crossing for both pedestrians and vehicles alike. A Barrier utilidor is probably not the most appropriate or advantageous in this situation. Instead, a vault system, generally hidden from view would seem to make the most sense as it becomes incorporated into the landscape base plane and allows for unfettered movement of the visiting public.

The required utilities which would need to be incorporated include one 2” fire protection water line, one (assumed) 2” culinary water line, one 6” sewer line and the requisite electrical and communication lines which are unknown in size but minimal in space requirements. An advantage of applying the vault system at this location is the reduction in crossing complications and transition zones. The only connection and “change-point” becomes the connection with the main infrastructure lines. As can be seen in Figures 56 & 57, this would entail adding enhanced hardscaping, such as sidewalks and small plazas, to areas of the Upper General Store property.

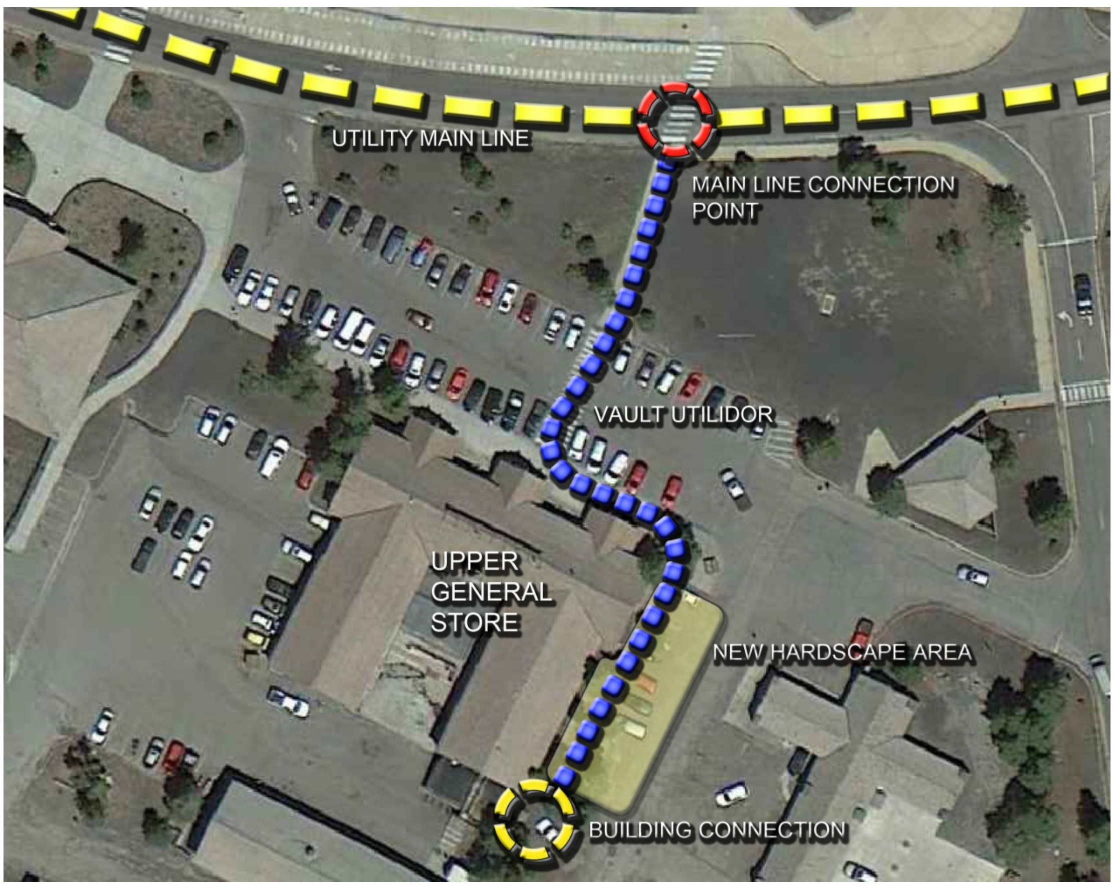


Figure 56. Upper General Store routing and points of connection. Utilizing vault utilidors in this region eliminates the hazards associated with conflict points found in the front of the store, a crowded and busy part of the Old Faithful area.

This utilidor system has the potential to save approximately 1,300 cubic yards of soil disturbance, based on a run length of approximately 390 feet utilizing a conventional trench, again, 15 feet deep and 6 feet wide.

Figure 57. Vault utilization at the general store. The advantage of a vault system here lays in its ability to avoid visitor-utility conflicts, while nearly eliminating trenching and remaining out of the visual landscape.

The area to the east of the Old Faithful Visitor Center is an important area due to its heavy visitor usage. It experiences large influxes of pedestrian traffic, much of it off-sidewalk, as visitors move from the parking lot to the visitor center and the geyser. This location also houses a large propane/natural gas tank as well as public restrooms.

The propane/ natural gas tank presumably feeds the new visitor center and utilidors in the region would be responsible for delivering gas to the visitor center and sewer, water and electricity to and from the public restrooms.

As this area is heavily traveled, and the utility runs relatively short (Figure 58), a Seat Wall utilidor would be an appropriate design solution. A Seat Wall would serve the dual functions of pedestrian circulation control and visitor comfort while accommodating necessary utilities with minimal vertical presence in the landscape. With its close proximity to the new visitor center, the Seat Wall could utilize both stone and concrete and continue to blend in with the surrounding visual landscape (Figure 59). Figure 60 details the connection of the public restroom with the necessary lift station converting the gravity sewer system into a short-run force main sewerage.

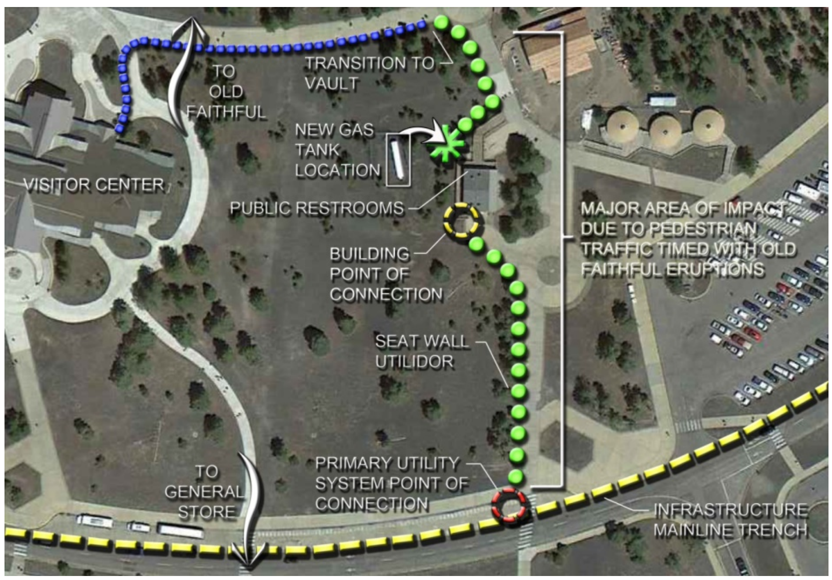


Figure 58. Plan view of utilidor runs connecting public restrooms and natural gas. Seat Wall utilidors in this area would provide circulation control, resting areas and an improved integration of the existing gas tank with the surrounding environment. Utilizing an aesthetic structural cover over the gas tank, integration between the utilidor and the tank structure can be achieved.

Figure 59. East-of-visitor center seat wall utilidor image. Leading to the public restrooms, the low profile of this utilidor style provides for edge definition and circulation control while providing rest areas and encouraging enjoyment of the space.

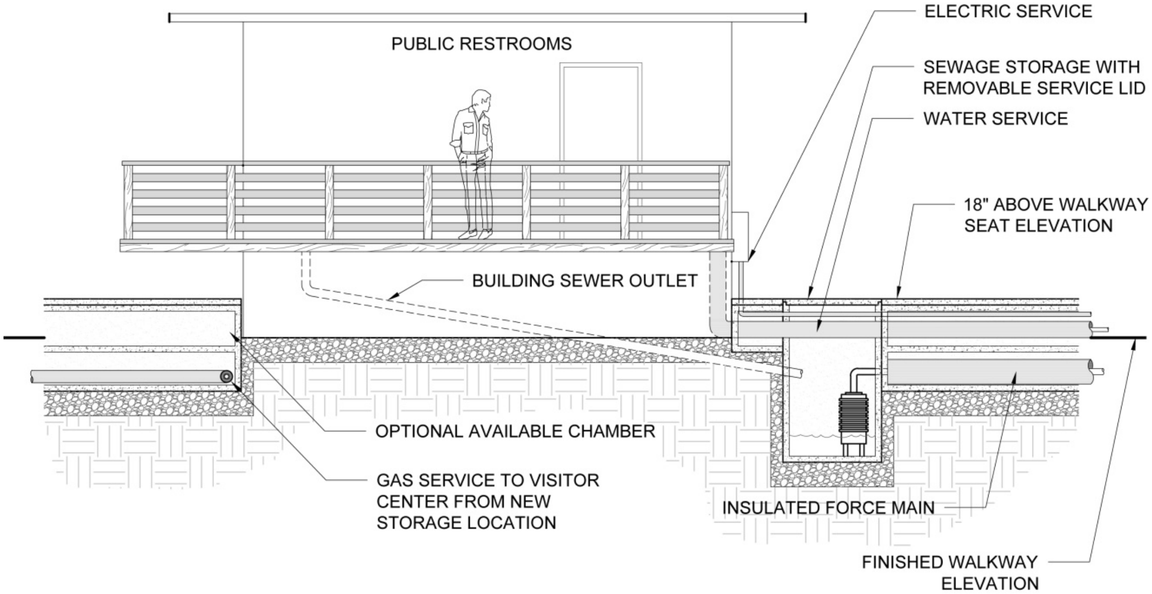


Figure 60. Public restroom connections. For general plan view connection detail concerning Seat Wall utilidor and sewage storage layout, refer back to Image 54.

While the exact utility line sizes feeding the public restrooms are unknown, the assumed line sizes of one 8”sewer line, one 1.5” water supply line and an electrical supply line could potentially save an estimated 967 cubic yards of excavation, based on utilizing surface utilidors instead of a conventional trench 15 feet deep, 6 feet wide and 290 feet long. In addition, adding the gas line into an utilidor structure would save an extra 167 cubic yards of excavated soil based on replacing an assumed existing trench 6 feet deep, 3 feet wide and 250 feet long.

Historic Zone Application

The Historic Zone has the potential to use a variety of the previously mentioned utilidor styles. The overriding concern in this zone is the minimization of visual intrusion on the historic character of Old Faithful Inn. Any utilidors used in this zone must be either completely hidden, or, blend in so well to the existing structural ambiance as to either go unnoticed or to be regarded as a complimentary addition. This is a difficult zone to design from a conceptual standpoint, as the existing utility system is a complex compilation of history and engineering. Concepts suggested herein are based on the idea that multiple utilidors would need to supply the requisite utilities to feed a building of this size.

The recommendations for this zone, on the south/southwest corner of the primary structure, include a Foundation Extension which can carry utilities through a transition from a Rail Barrier-style utilidor on the southwest corner of the structure. Figure 61 shows the potential for an extension utilidor to blend with the foundation of its associated structure. The foundation of the lodge is created of large, exposed stone. It is assumed there is a concrete structure behind the stone façade, and this stone could be theoretically removed and then replaced atop the extension utilidor housing, creating the illusion of the same stone foundation, now only improved with the inclusion of building utilities. Further, if located in such a way to not be in direct view of the majority of visitors, scenic quality impacts can be minimized.

Figure 61. Foundation extension abstract imagery.

By transitioning to a Rail Barrier instead of a larger stone constructed barrier, the rustic simplicity of the landscape, with the Old Faithful Inn maintaining visual dominance, could be enhanced and converted to include the necessary railing visual elements found in the area. This would include, primarily, the exiting sewage system servicing the Inn. The Rail Barrier would be required to maintain the same scale, color and texture of the existing railings found in the area.

As well, a Foundation Extension utilidor should avoid, if possible, application in visually sensitive areas, such as the front or main entrances of the building, but instead be relegated to more unobtrusive points of connections (Figure 62), in locations where a Barrier or other visually oriented solution would not be practical.

A Foundation Extension would limit further the needed excavation over that of traditional utility connections or even that of the hybrid vault-style utilidors covered earlier in this text. The connection between the extension housing and that of a vaulted Rail Barrier would be similar to that found in Images 48, 49 and 55, utilizing a transition chambers to change grades and housings. Points of connections for the extension housing would be similar to that found in Images in 53 and 54. Ultimate placement of pipe location entrances into the utilidor would be dependent on final location and design based on actual utility specifications found on site.

Groundwater and hydrothermal features could possibly create problems for a vault system in this region. If surface construction of sidewalks and roadways is not possible, it may be necessary to utilize full surface Barrier utilidors in place of Rail Barrier vault style systems. Concrete structures in this area should not be seriously affected by the hydrothermal features as these systems are wet systems with a highly alkaline composition.

Figure 62. Plan view of Old Faithful Inn points of connection and utilidor routing.

Natural Zone Application

In the Natural Zone, utilidors utilizing materials matching the existing visual landscape are most suitable. In this instance, the native flora consists of fairly sparse evergreen forests punctuated with open expanses of bare soil, often times consisting of the siliceous sinter deposits associated with wet hydrothermal systems. Figure 63 portrays the possibility a barrier rail style of utilidor has in blending with a more natural visual environment.

Figure 63. Natural zone rail barrier imagery.

The utilidor style recommended in this region would primarily consist of the hybrid vault styles; the Large Vault, Small Vault or Rail Barrier. These utilidors would be most suitable due to the fact they are simplistic in nature; neither costing great amounts nor disturbing the visual aesthetic of the area.

As the Natural Zone is heavily dominated by the verticality of vegetation (trees), utilizing a hybrid vault style such as the Rail Barrier would allow for a distinctive form of pedestrian control that does not become a dominating element in the visual landscape. Achieving a utility connection invisible to the average visitor would be possible utilizing Small or Large Vaults, but these options would provide little in the way of creating a visual aesthetic suitable for a pathway through the forest. The Rail Barrier would allow for this aesthetic, while also creating a corridor easily found for the purposes of maintenance, repair and replacement.

Utilidor design in this zone should be heavily influenced by wood and natural color tones. Preservation of the natural feel of this zone dictates that the utilidor remain low and unobtrusive. Building or structural connections would be highly controlled by final designs, but would also utilize the transition chambers covered earlier, allowing for changes in utilidor structure and alterations in grade and elevation.

CHAPTER VI

CONCLUSION

The inclusion of utilidor construction into the master planning procedures of Yellowstone National Park has the potential to increase flexibility in visitor services expansion. By utilizing aesthetic features and design styles in the planning and construction processes, surface utilidor placement can be achieved while still attaining the visual goals set forth in National Park Service culture, history and legal precedent.

By implementing utilidors in a surface capacity, sub-surface environmental protection of sensitive geothermal resources of Yellowstone National Park can be achieved over time. Further research of this concept holds the potential for providing avenues for supported research, the development and expansion of the ideas of systems resilience, and the development of low-impact infrastructure outside the scope of the National Park Service.

The use of utilidors in a functional and aesthetic capability is still in its infancy and numerous areas of research must still be carried out if these ideas are to ever achieve reality. These future areas of research could include, among others, exact engineering specification and standards of utility components and structural requirements, effects of frost heave on joint placement along the utilidor line, seismic solutions for secure placement of lines within a small scale utilidors, and continued research into impacts of climate change on the depth of ground frost penetration. Research on public perception of surface placement of utilidors in iconic landscapes could also become an important element in the cultural requirements of utilidor implementation.

Finally, as mentioned previously in this work, the concepts provided in this work are intended to be based in design and development, and not in exacting finalization of specific details and construction techniques. It is expected that the future research outlined above would be supported and completed as a part of the planning processes of the National Park Service.

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APPENDICES

Appendix A: Glossary

Backflow: A term in plumbing for an unwanted flow of water in the reverse direction. It can be a serious health risk for the contamination of potable water supplies with foul water.*

Caldera: A cauldron-like volcanic feature usually formed by the collapse of land following a volcanic eruption. They are sometimes confused with volcanic craters. The word comes from Spanish *caldera*, and this from Latin *caldaria*, meaning "cooking pot."*

Carbonated Front: The advancement of chloride ions through a layer of concrete which lowers the pH (acidifies), ultimately reducing the passive protection highly alkaline concrete provides to interior steel reinforcing bar.

Class F Fly Ash: Refers to ash produced during combustion of coal. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) and calcium oxide (CaO), both being endemic ingredients in many coal-bearing rock strata.*

Clean Air Act: A United States federal law designed to control air pollution on a national level. It requires the Environmental Protection Agency (EPA) to develop and enforce regulations to protect the public from airborne contaminants known to be hazardous to human health.*

Clean Water Act: The primary federal law in the United States governing water pollution. Passed in 1972, the act established the goals of eliminating releases of high amounts of toxic substances into water, eliminating additional water pollution by 1985, and ensuring that surface waters would meet standards necessary for human sports and recreation by 1983.*

Concrete Frost: Occurs when water-saturated soil freezes, creating an impenetrable barrier for water infiltration. Normally occurs when late season rains, in the absence of snow, are followed by extreme cold.**

Decay: A biological process in which fungi and bacteria break down organic matter. Can lead to the fast destruction of organic building materials.

Ecosystem: A community of living organisms (plants, animals and microbes) in conjunction with the nonliving components of their environment (things like air, water and mineral soil), interacting as a system.*

Ecosystem Function: The interactions between organisms and the physical environment, such as nutrient cycling, soil development, water budgeting, and flammability.****

Enabling Legislation: A political action by which a legislative body grants an entity authorization or legitimacy of power to take certain actions.*

Environment: The biotic and abiotic surrounding of an organism or population, and includes the factors that have an influence in their survival, development and evolution. The term environment can refer to different concepts, but is often used as a short form for the *biophysical environment*.*

Environmental Stewardship: refers to responsible use and protection of the natural environment through conservation and sustainable practices.*

Force Main Sewer: A sewer system utilizing collection tanks and pumps. Allows for sewer systems to overcome barriers of gravity and inability to trench to adequate depths.

Freeze-Thaw Cycle: The numerous cycles of cold to warm to cold which mobilizes water and is a key element of weathering.

Friction Head: In a hydraulic system the part of a head of water or of another liquid that represents the energy that thesystem dissipates through friction with the sides of conduits or channels and through heating from turbulent flow.***

Friction Loss: The loss of energy or "head" that occurs in pipe flow due to viscous effects generated by the surface of the pipe.*

Frost Heave: An upwards swelling of soil during freezing conditions caused by an increasing presence of ice as it grows towards the surface, upwards from the depth in the soil where freezing temperatures have penetrated into the soil.*

Fumarole: An opening in a planet's crust, often in the neighborhood of volcanoes, which emits steam and gases such as carbon dioxide, sulfur dioxide, hydrogen chloride, and hydrogen sulfide. The steam is created when superheated water turns to steam as its pressure drops when it emerges from the ground.*

Geyser: A spring characterized by intermittent discharge of water ejected turbulently and accompanied by a vapor phase (steam). Surface water works its way down to an average depth of around 2,000 metres (6,600 ft) where it contacts hot rocks. The resultant boiling of the pressurized water results in the geyser effect of hot water and steam spraying out of the geyser's surface vent.*

Geyser Basin: A collection of geysers within a single geographically located valley, or basin.

Geothermal Resource Area: An area or region studied and utilized for geothermal energy extraction due to its high concentration of geothermal activity.

Granular Frost: Occurs when dry soils fall below the freezing point. Ice crystals form in the soil profile, but air space remains, allowing water infiltration to occur. Normally occurs when soils freeze in the absence of rain or snow.**

Grinder Pump: A wastewater conveyance device. Waste from water-using household appliances (toilets, bathtubs, washing machines, etc.) flows through the home's pipes into the grinder pump's holding tank. Once the wastewater inside the tank reaches a specific level, the pump will turn on, grind the waste into a fine slurry, and pump it to the central sewer system or septic tank.*

Heat Trace: A system used to maintain or raise the temperature of pipes and vessels. Trace heating takes the form of an electrical heating element run in physical contact along the length of a pipe. The pipe must then be covered with thermal insulation to retain heat losses from the pipe. Heat generated by the element then maintains the temperature of the pipe.*

Hot Spring: A spring that is produced by the emergence of geothermally heated groundwater from the Earth's crust.*

Hydrothermal System: A system of interconnected subterranean circulating hot water which can result in numerous hot springs, geysers and boiling pools.

Mission 66: A United States National Park Service ten-year program that was intended to dramatically expand Park Service visitor services by 1966, in time for the 50th anniversary of the establishment of the Park Service.*

Mud Pot: An acidic hot spring or fumarole with limited water. It usually takes the form of a pool of bubbling mud. The acid and microorganisms decompose surrounding rock into clay and mud.*

NEPA (National Environmental Policy Act): A United States environmental law that established a U.S. national policy promoting the enhancement of the environment and also established the President's Council on Environmental Quality (CEQ). As one of the most emulated statutes in the world, NEPA has been called the modern-day equivalent of an "environmental Magna Carta."*

Passivation: In physical chemistry and engineering, this refers to a material becoming "passive," that is, being less affected by environmental factors such as air and water. Passivation involves a shielding outer-layer of corrosion, which can be applied as a micro-coating, or which occurs spontaneously in nature.*

Policy Framework: A logical structure that is established to organize policy documentation into groupings and categories that make it easier for employees to find and understand the contents of various policy documents. Policy frameworks can also be used to help in the planning and development of the policies for an organization.*

Portland Cement: The most common type of cement in general use around the world, used as a basic ingredient of concrete, mortar, stucco, and most non-specialty grout. It usually originates from limestone. It is a fine powder produced by grinding Portland cement clinker (more than 90%), a limited amount of calcium sulfate(which controls the set time) and up to 5% minor constituents as allowed by various standards such as the European Standard EN 197-1.*

Pressure Loss: Also known as Pressure Drop, it is the difference in pressure between two points of a fluid carrying network. Pressure drop occurs when frictional forces, caused by the resistance to flow, act on a fluid as it flows through the tube. The main determinants of resistance to fluid flow are fluid velocity through the pipe and fluid viscosity. Pressure drop increases proportional to the frictional shear forces within the piping network. A piping network containing a high relative roughness rating as well as many pipe fittings and joints, tube convergence, divergence, turns, surface roughness and other physical properties will affect the pressure drop. High flow velocities and/or high fluid viscosities result in a larger pressure drop across a section of pipe or a valve or elbow. Low velocity will result in lower or no pressure drop.*

R-Value: A measure of thermal resistance used in the building and construction industry. Under uniform conditions it is the ratio of the temperature difference across an insulator and the heat flux (heat transfer per unit area per unit time) through it.*

Rebar (Reinforcing Bar): A common steel bar or mesh of steel wires commonly used as a tension device in reinforced concrete and reinforced masonry structures, to strengthen and hold the concrete in compression.*

Reformer Pocket: An important component of vacuum sewer system piping design. These pockets allow the pressure differential to reform using re-pooled sewage to recreate the “plug” necessary for the system to operate.

Resilience (Ecological): The ability of an ecosystem to absorb changes and still be able to exist in a functioning capacity.

Rut: Also known as the Rutting Period, this is the mating season of ruminant animals such as deer, sheep, elk, moose, bison, caribou, ibex, goats, pronghorn and Asian and African Antelope.*

Sanitary Sewer: A separate underground carriage system specifically for transporting sewage from houses and commercial buildings to treatment or disposal.*

Siliceous Sinter: Hot-spring deposits that initially form as silica deposits from discharging alkali chloride thermal fluids.*****

Spalling: Spall are flakes of a material that are broken off a larger solid body. Spalling and Spallation both describe the process of surface failure in which spall is shed.*

Stop Waste (Valve): A type of plug valve that when in a closed position drains the piping above or beyond it. When the valve is turned a quarter turn to shut it off, a small port or hole in the valve body is uncovered. Permitting water above the valve to drain out, preventing a freeze up in cold weather. Stop-and-waste valves are used mainly on small-diameter water piping.******

Structural Integrity: An aspect of engineering which deals with the ability of a structure to support a designed load (weight, force, etc...) without breaking, tearing apart, or collapsing, and includes the study of breakage that has previously occurred in order to prevent failures in future designs.*

Sustainable Development: An organizing principle for human life on a finite planet. It posits a desirable future state for human societies in which living conditions and resource-use meet human needs without undermining the sustainability of natural systems and the environment, so that future generations may also have their needs met.*

Thermal Equilibrium: In a system for itself means that the temperature within the system is spatially and temporally uniform. Thermal equilibrium as a relation between the physical states of two bodies means that there is actual or implied thermal connection between them, through a path that is permeable only to heat, and that no energy is transferred through that path.*

Thermal Stress: The comprehensive effects of severe cold and numerous freeze thaw cycles, each of which causes little damage by themselves, but in aggregate can cause structural failure.

Travertine: A terrestrial sedimentary rock, formed by the precipitation of carbonate minerals from solution in ground and surface waters, and/or geothermally heated hot-springs.*

Utilidor: A passage built underground or aboveground to carry utility lines such as electricity, water and sewer pipes.*

Utilitarianism: A theory in normative ethics holding that the proper course of action is the one that maximizes utility, usually defined as maximizing happiness and reducing suffering.*

Vacuum Sewer: A system which uses the differential pressure between atmospheric pressure and a partial vacuum maintained in the piping network and vacuum station collection vessel. This differential pressure allows a central vacuum station to collect the wastewater of several thousand individual homes, depending on terrain and the local situation. Vacuum sewers take advantage of available natural slope in the terrain and are most economical in flat sandy soils with high ground water.*

Valve Pit: A vault in which piping valves can be located, reducing the corrosion and damage associated with direct ground burial.

Watershed: An extent or an area of land where surface water from rain and melting snow or ice converges to a single point at a lower elevation, usually the exit of the basin, where the waters join another waterbody, such as a river, lake, reservoir, estuary, wetland, sea, or ocean.*

Weathering: The breaking down of rocks, soil and minerals as well as artificial materials through contact with the Earth's atmosphere, biota and waters. Weathering occurs *in situ*, or "with no movement", and thus should not be confused with erosion, which involves the movement of rocks and minerals by agents such as water, ice, snow, wind, waves and gravity.*

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* Definition taken in whole, or in part, from: www.wikipedia.org

** Definition taken in whole, or in part, from: Edwards, Scalenghe and Freppaz, 2007

*** Definition taken in whole, or in part, from: http://dictionary.reference.com

**** Definition taken in whole, or in part, from: http://www.biology-online.org

***** Definition taken in whole, or in part, from: https://researchspace.auckland.ac.nz/handle/2292/6047

****** Definition taken in whole, or in part, from: http://dictionary.babylon.com/stop-and-waste_valve/

Apendix B: Image Archives

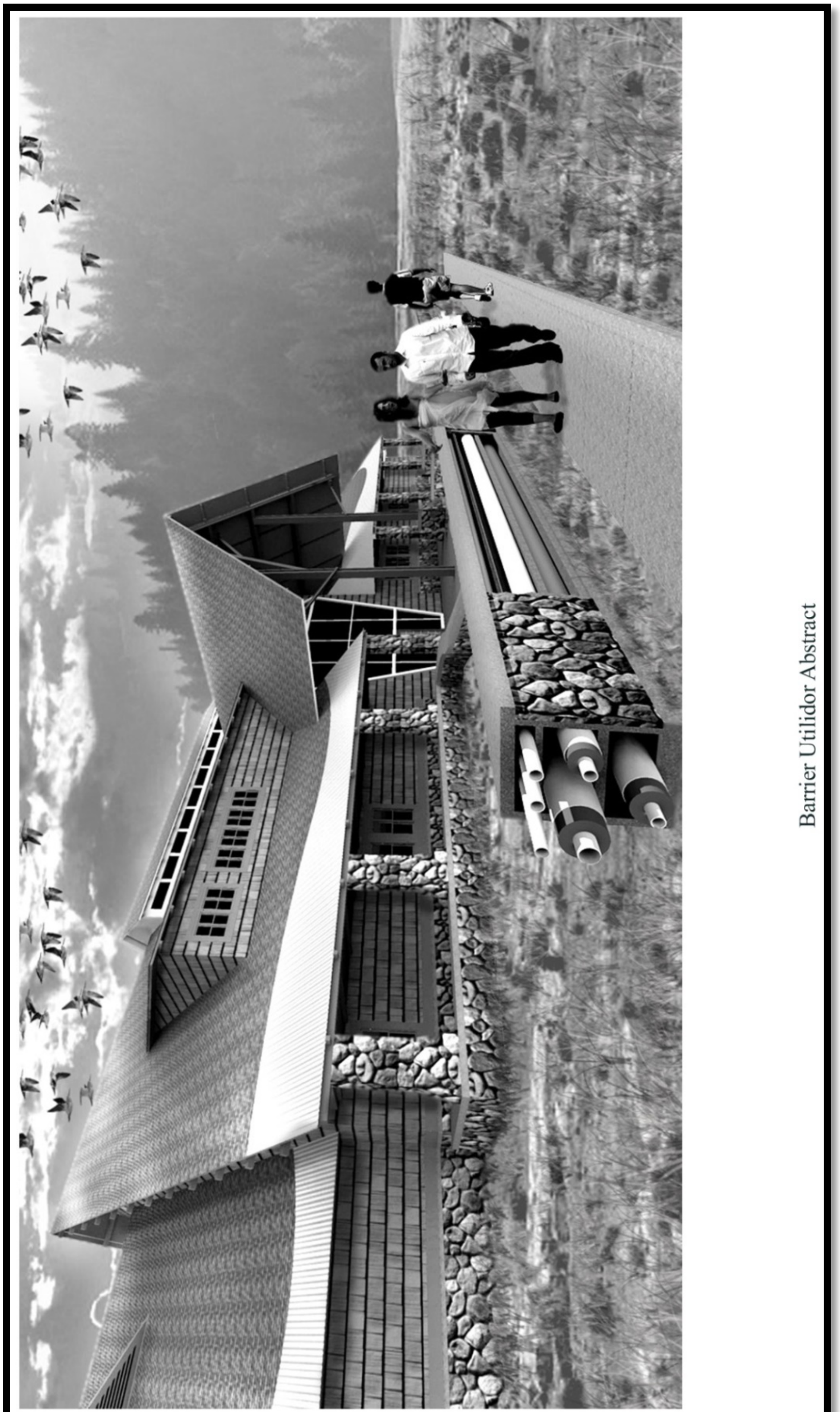

Figure 64. Barrier Utilidor Abstract

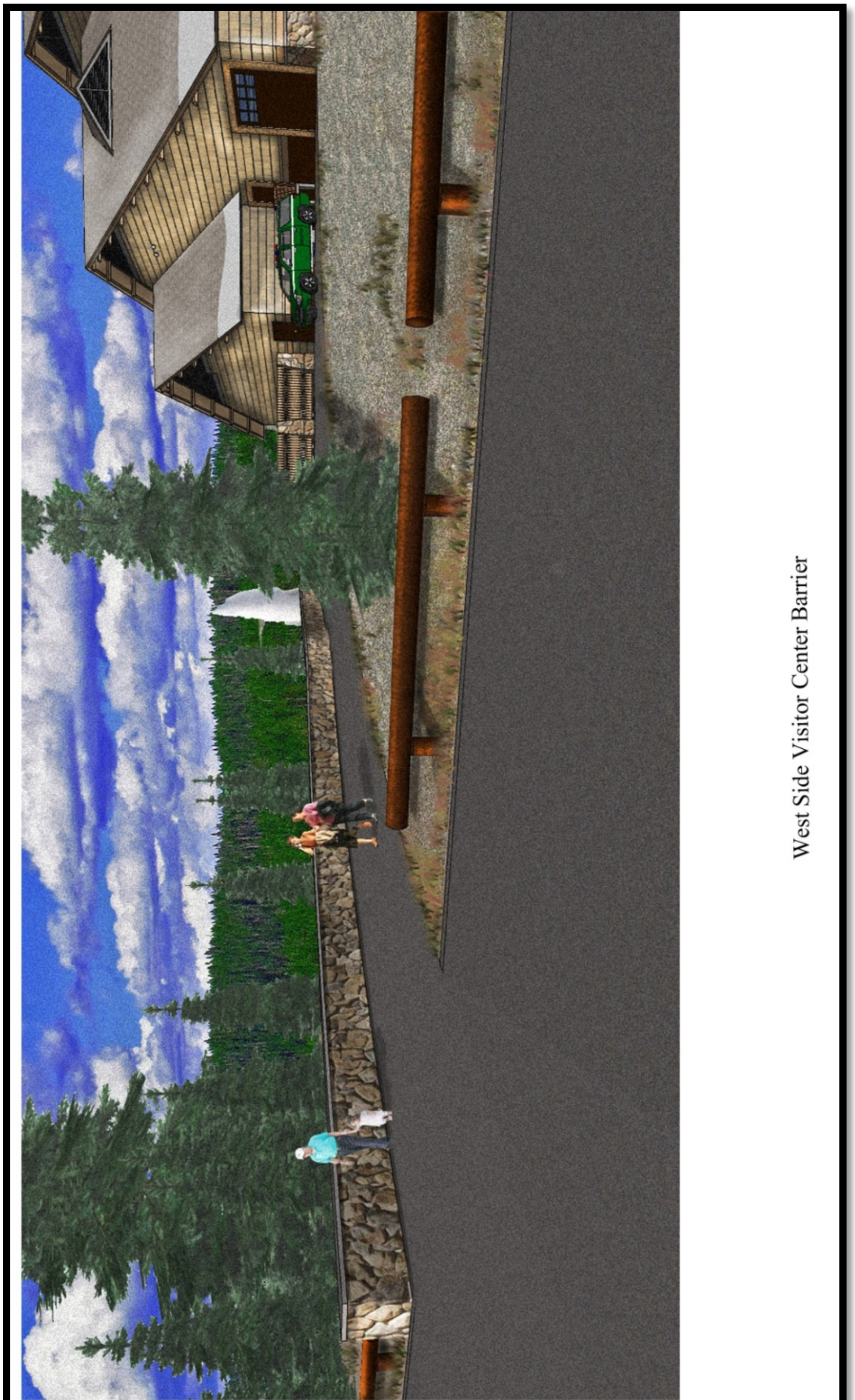

Figure 65. West Side Visitor Center Barrier

Upper General Store Utilizing Sidewalk Vaults

Figure 66. Upper General Store Utilizing Sidewalk Vaults

Old Faithful Inn Foundation Extension

Figure 67. Old Faithful Inn Foundation Extension

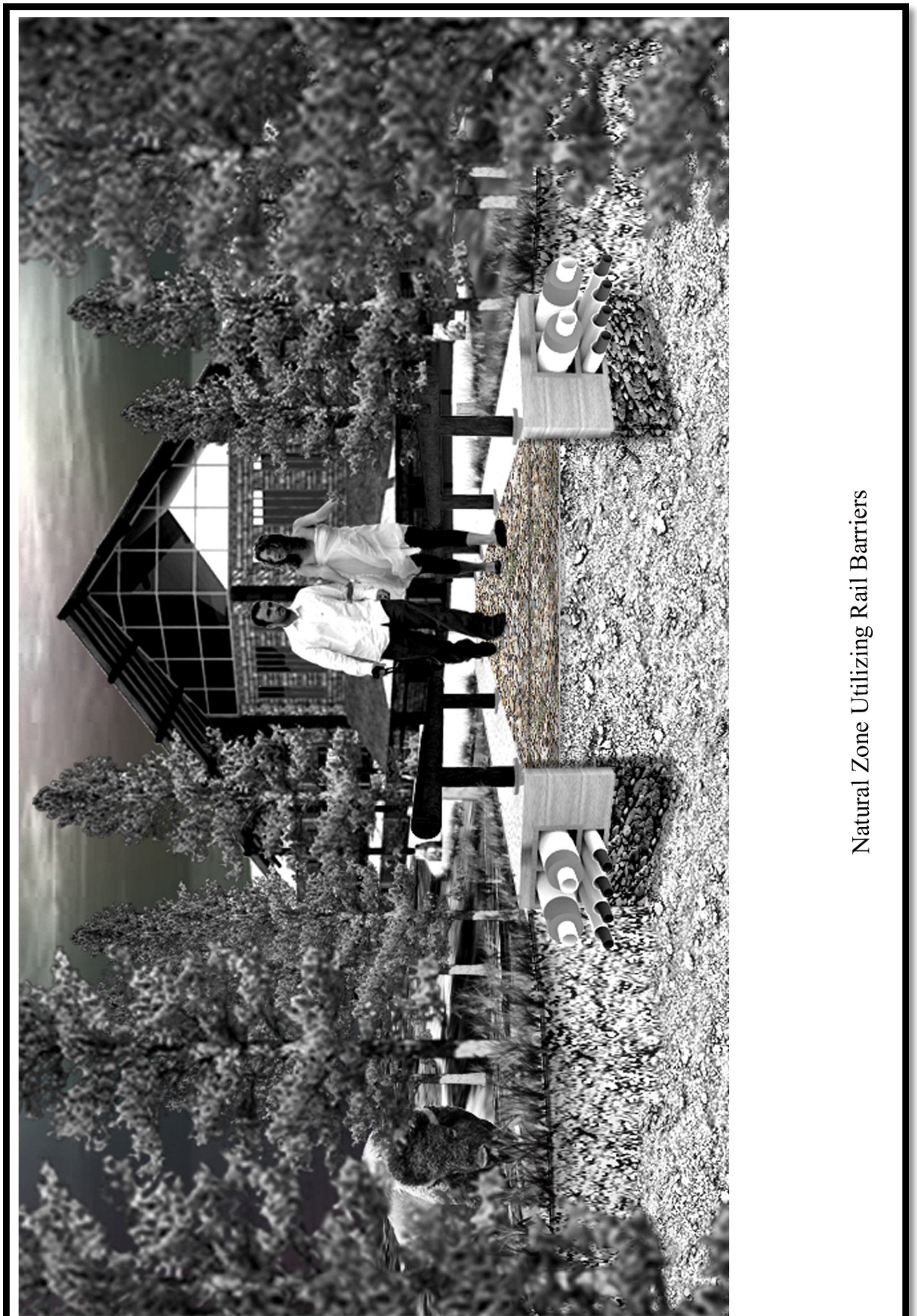

Figure 68. Natural Zone Utilizing Rail Barriers

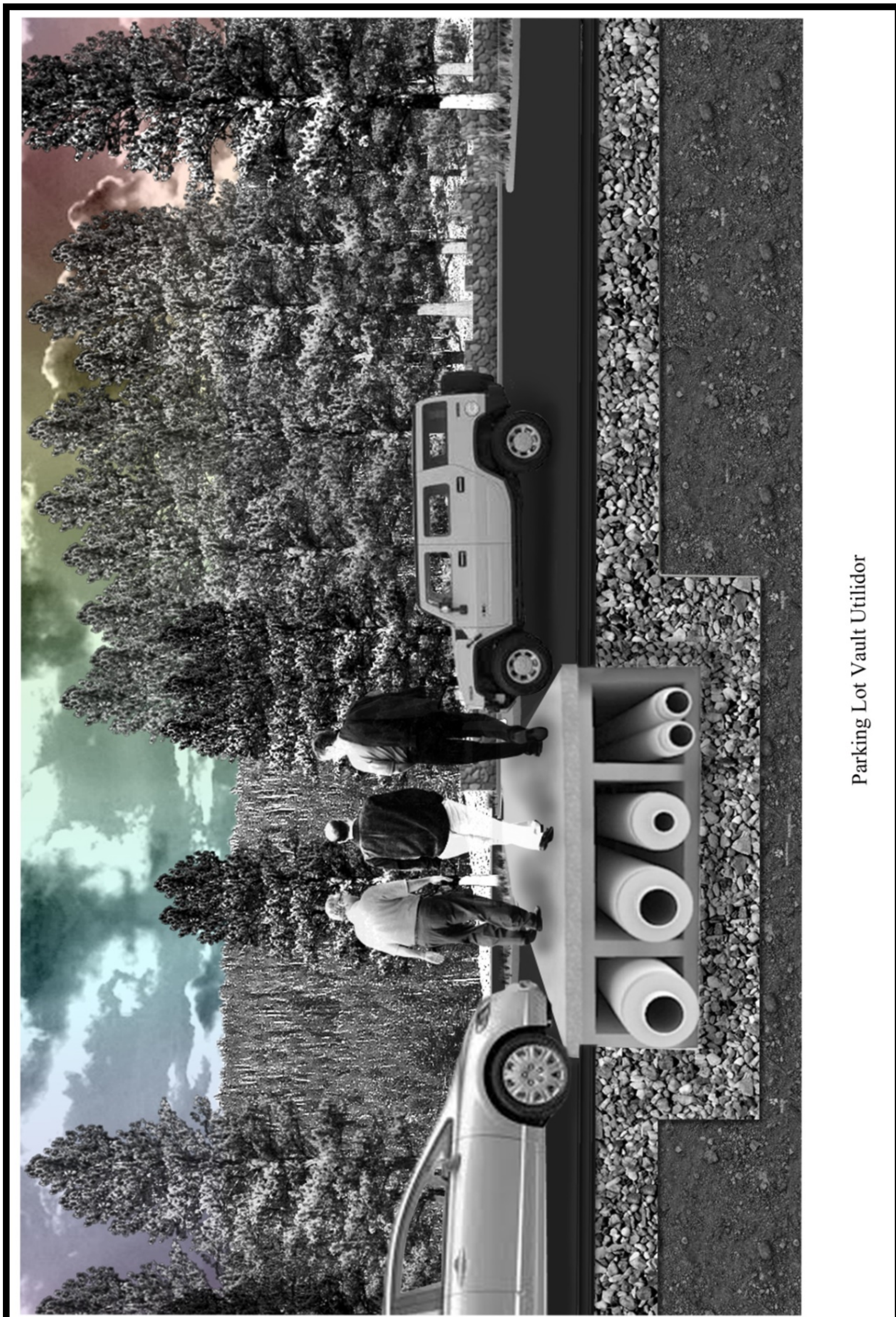

Figure 69. Parking Lot Vault Utilidor

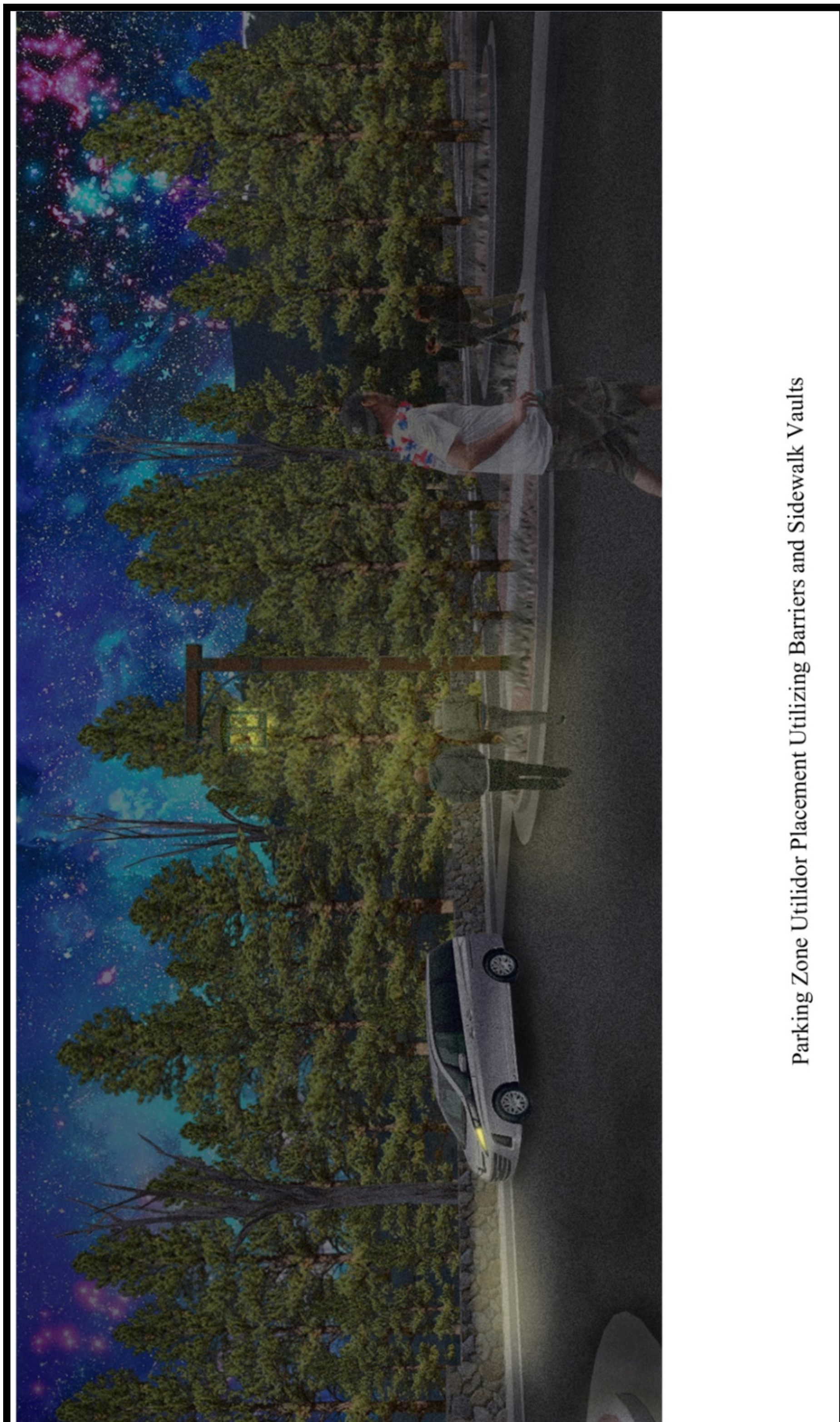

Figure 70. Parking Zone Utilidor Placement Utilizing Barriers and Sidewalk Vaults

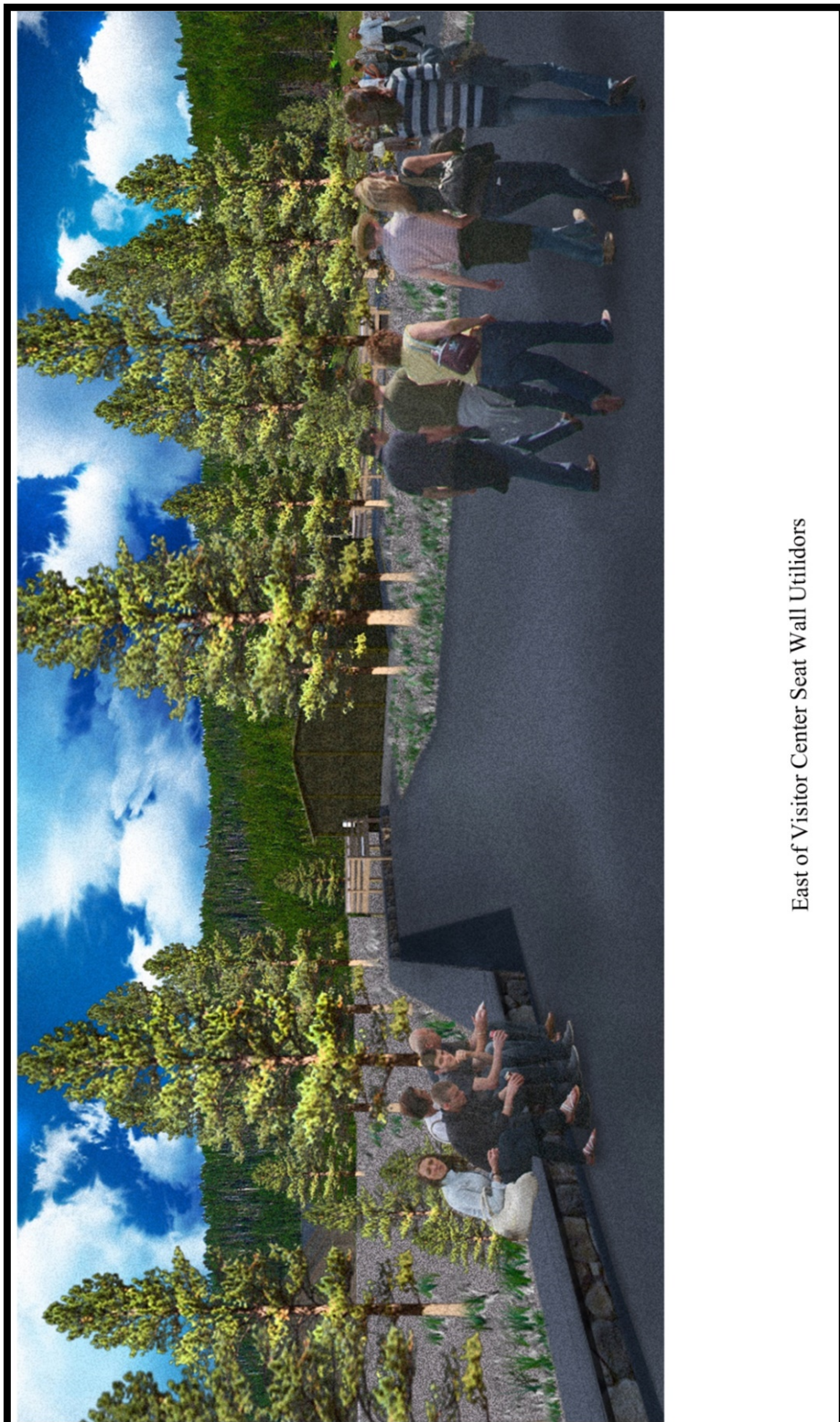

Figure 71. East of Visitor Center Seat Wall Utilidors

…Now's the time to turn the tide
Now's the time to fight
Let us not go gently
To the endless winter night
Now's the time to make the time
While hope is still in sight…

-Neil Peart